GAS AND OIL ENGINES
RUNNING AND MAINTENANCE

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by

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A.R.T.C. A.M.I.Mech.E.

A HANDBOOK FOR THE PRACTICAL MAN AND THE STUDENT

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PREFACE

This work was started by Mr. Orkney, B.Sc., now in U.S.A., who received many blue-prints and much data from engine-makers. The author has used these, and has referred to them in the text. As many of the larger works on the subject of gas and oil engines have been consulted in getting together this work, the author would like to acknowledge the free use of those books and institutions' papers.

The author is especially indebted to Mr. Robert Smith, B.Sc., and Mr. Wm. Ferguson, B.Sc., also to the editor, Mr. James Smith, B.Sc., for assistance with arrangements, drawings and proof reading.

P. S. CALDWELL.

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INTRODUCTION

Most text-books, particularly those in a series of small handbooks such as this, are at best a compromise. To attempt to cover a large field results in very inadequate treatment, and a detailed analysis of any one small point is of very limited application and usefulness. It seems well, therefore, to recognise at the commencement the limitations of such a handbook.

The practical man, for whom it is intended, does not desire to read through an exhaustive thermo-dynamic treatise; the student, to whom it should prove a useful primer, has not the necessary time at his disposal. Hence the book is small and does not demand a knowledge of much theory or an extensive practical experience. Its aim is to be concise and clearly reasoned.

Petrol engines of all classes are omitted, since they are already so excellently and fully dealt with, particularly as applied to automobiles. Similarly, high-tension ignition will be found fully dealt with in conjunction with petrol engines, where it seems to find its true field. In this volume it is desirable to confine attention to low-tension and other forms of ignition appliances.

Diesel engines form such a highly specialised branch of oil engine development that they are treated specially in a companion volume of the series, and we are content here to describe only their fundamental principles as an excellent introduction to the subject of "Semi-Diesels," which bid fair to capture first place among small oil engines.

In general, the detail consideration of large high-power plants will only be very slightly introduced in this work. Such high-power plants are usually under the supervision of a highly skilled staff, and again the fundamental principles underlying small plant will be found to be almost the same as for the larger plants. It will be found that the same troubles have to be overcome in all sizes of engines, and if

we can impart the fundamental principles these troubles will not worry the attendant very much. It is hoped to cover all types, and not just a few more popular modern designs. The attendant will thus be able to make a really intelligent use of such aids as trouble-tracing charts, and may also gain a fuller knowledge of his plant than would otherwise be possible.

CHAPTER I

GAS ENGINES

FEW people nowadays are ignorant of the principle of operation of the gas engine. It may well lay claim to be the first real internal combustion engine, and in the year 1862 a French engineer claimed that his gas engine could have the largest cylinder capacity with the smallest circumferential surface of any prime mover ; that it had the greatest possible expansion and highest pressure at the beginning of the stroke. It was this engineer who first used the four-stroke cycle, which has been known for a long time as the " Otto " cycle. This cycle is the commonest, and, for small engines, is undoubtedly the best.

Beginning with the suction, or induction, stroke (refer to Fig. 1),

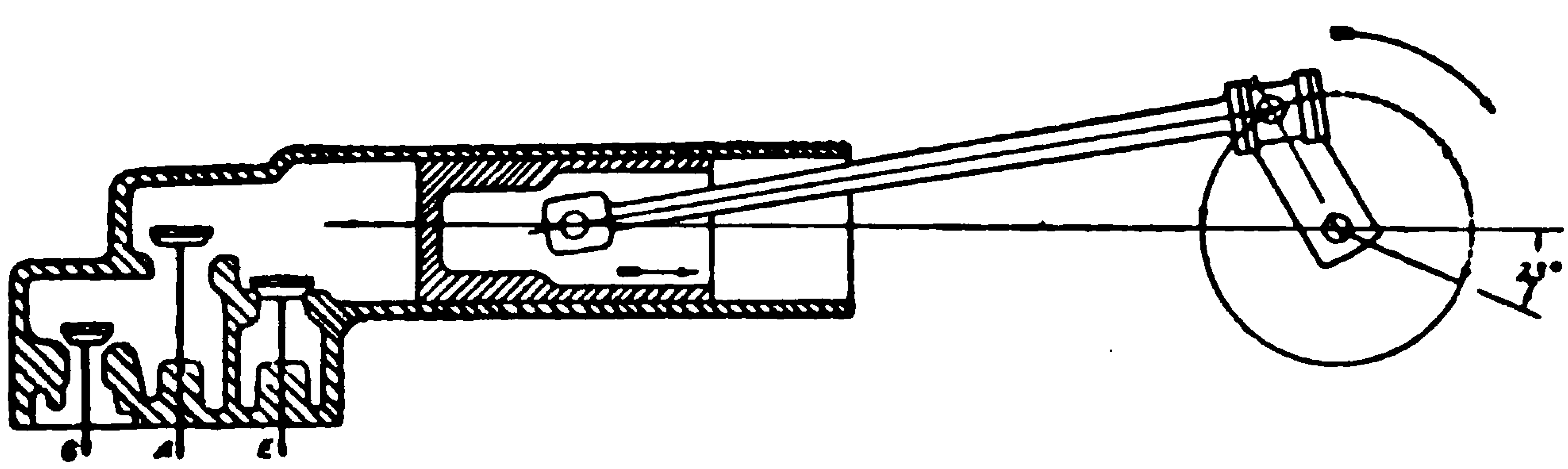


FIG. 1.

SKETCH DIAGRAM OF ENGINE ON SUCTION STROKE.

the gas valves are opened and the outgoing piston draws in a mixture of gas and air in correct proportions for exploding. The dotted arc represents the angle moved through by the crank from the time of opening to the time of closing of gas and air valves, and thus constitutes a timing diagram. During this stroke the pressure in the cylinder falls to 2 or 3 lb. below that of the atmosphere. It will be noticed that the valves only close after the piston has begun the return stroke. The incoming gases have been forced to travel at such a high speed into the cylinder that they continue to pile themselves in, even after the suction, which caused them to move, has ceased. This increases the charge of gases in the cylinder and gives, in consequence, more power. In high-speed engines the duration of open-

ing may be increased; the figures given are merely representative ones.

All valves being closed, the second, or compression, stroke takes place (see Fig. 2). The power required to compress the charge is obtained from the flywheel, but is by no means lost, since the energy so absorbed heats up the gases and a much more effective explosion

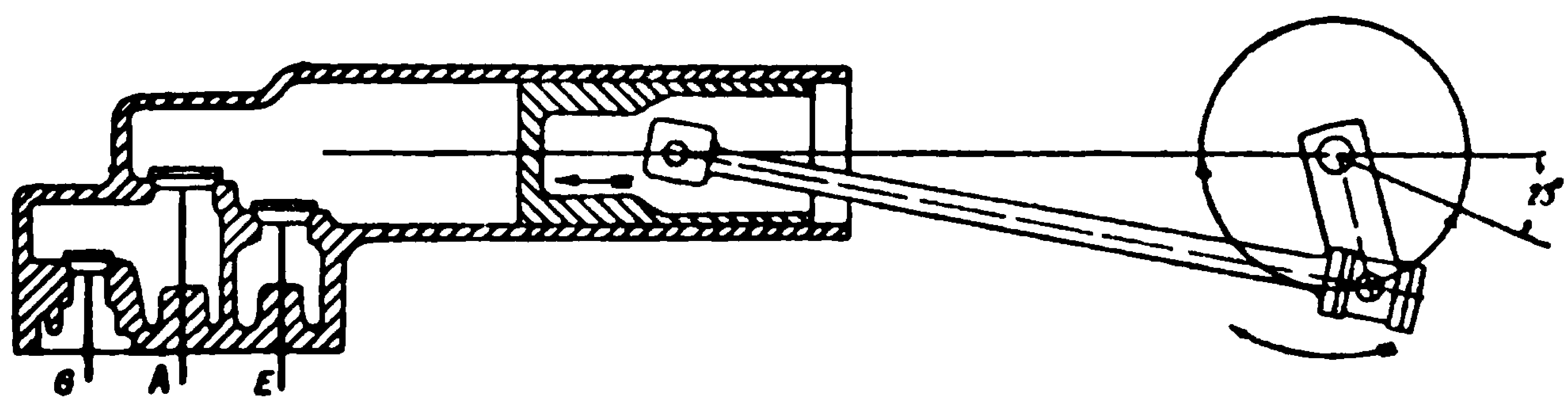


Fig. 2.
Sketch Diagram of Engine on Compression Stroke.

is obtained. The higher the compression the more efficient will be the engine, and hence more power is obtained from the same amount of gas. This is proved by both theory and tests, but the practical limit for ordinary town gas and air occurs about 80 lb. per square inch, since a higher pressure would so heat the mixture as to pre-ignite it; that is, the mixture would explode spontaneously

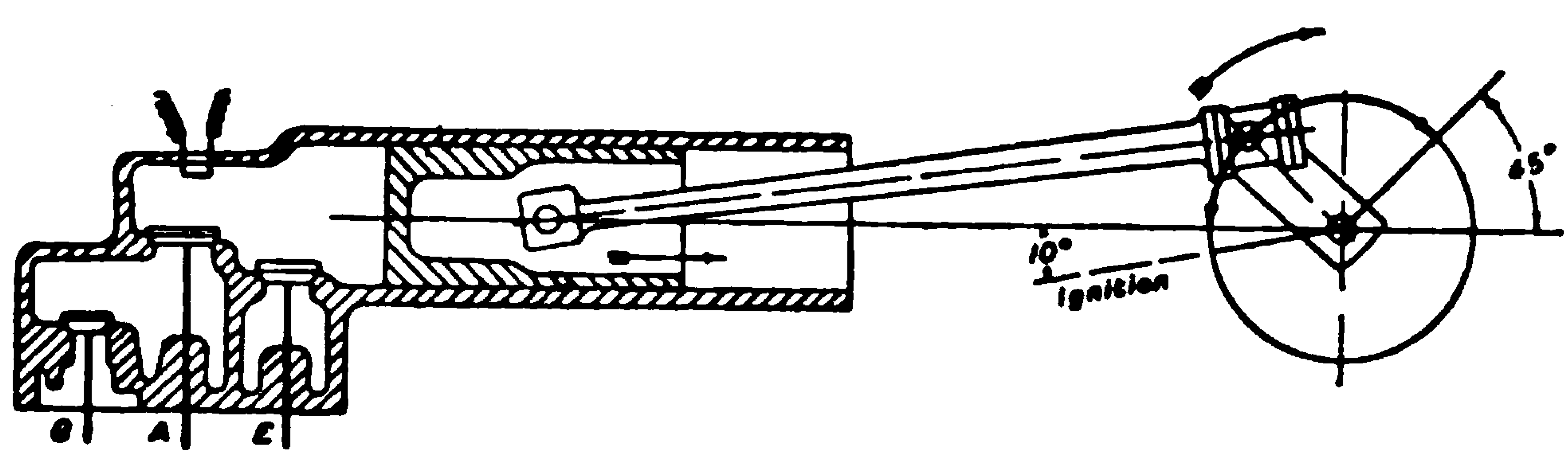


Fig. 3.
Sketch Diagram of Engine on Working Stroke.

before the end of the compression stroke. This pre-ignition not only reduces the power, but results in dangerously high pressures in the cylinder, straining all parts of the engine excessively. Poorer power gases, such as blast furnace gas, can be more highly compressed with advantage.

The third stroke is the only one of the cycle which produces power, and it is variously termed the "power," "working," or "explosion" stroke (see Fig. 3). Since the mixture takes a measurable time in which to become fully ignited, the ignition is arranged to commence, as shown, some time before the end of the compression stroke, so that

the full explosion pressure of from 350 to 500 lb. per square inch may be attained at the beginning of the power stroke so as to reap full benefit from the subsequent expansion. The faster the engine runs the earlier may this ignition point be arranged, since the time taken by the explosion remains the same. On starting up the engine it is imperative to retard the ignition point until after the piston has passed the "dead-centre," otherwise a back fire would result and the engine be forced round in the wrong direction, possibly with disastrous results. The exhaust valve *E* is timed to commence opening about 45 degrees before the end of the stroke so that it may be well open and most of the remaining pressure relieved before the piston commences the final stroke of the cycle. Later, when we discuss indicator diagrams, the effect on the expansion line will be

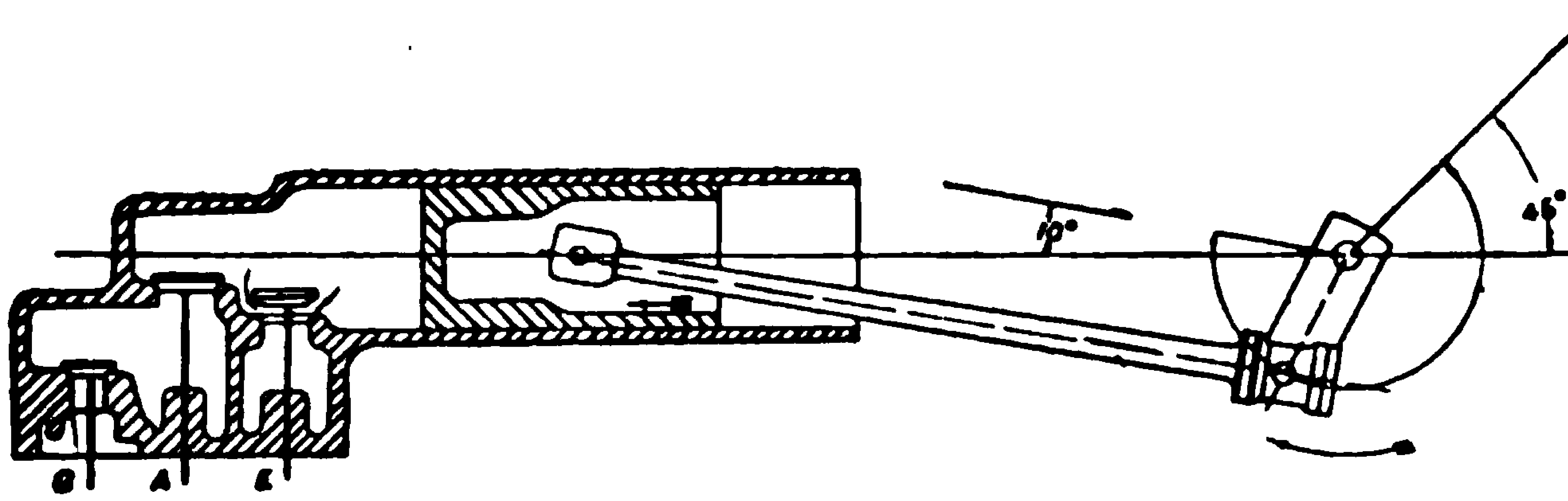


FIG. 4.
SKETCH DIAGRAM OF ENGINE ON EXHAUST STROKE

noticed—a sudden drop takes place at release point, or where the exhaust valve opens.

Throughout the whole of the fourth or exhaust stroke (Fig. 4) the exhaust valve remains open and the burnt gases are swept out by the advancing piston. Here again it is advantageous to delay the final closing of the valve until a few degrees after the dead-centre, since the rush of exhaust gases in the exhaust pipe is capable of producing a partial vacuum in the cylinder. It must be remembered, of course, that one of the main advantages of this opening of the valves earlier and closing them later than would at first glance seem advisable is that the valves have thus the opportunity of rising well off their seatings, and offer an unrestricted passage to the gases by the time the speed of the piston demands it.

It will be noticed from the combined timing diagram (Fig. 5) that the inlet valves have started to open before the exhaust valve has completely closed, but this slight overlapping entails no loss of the fresh fuel mixture, since all gas speeds are very low here and the actual valve openings very small, and hence insufficient time elapses

to enable the fresh mixture to have travelled as far as the exhaust valve before the latter has closed.

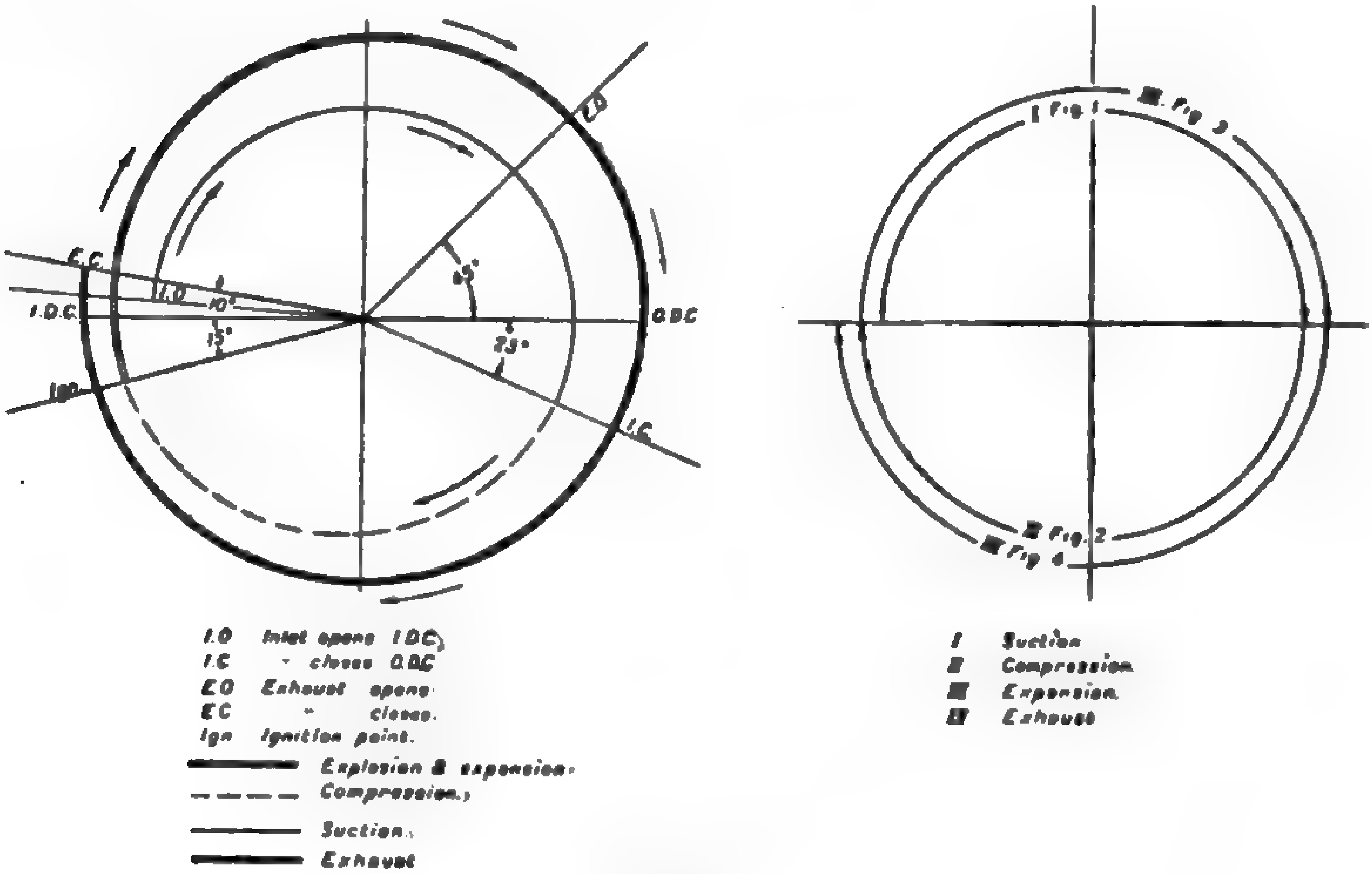


Fig. 5.

Combined Timing Diagram.

The four-stroke or "Otto" cycle just detailed gives a power impulse only once in two revolutions, so the necessity for the large flywheels fitted to gas engines is apparent, particularly when one considers the explosive nature of these impulses and the immediately preceding compression stroke with its large demand for power from the flywheel. Because of its relative simplicity, however, it is invariably used for small gas engines. The two-stroke principle requires additional gas and air pumps, so is reserved for really high-power sets. The Koerting double-acting engine is typical of these (Fig. 6).

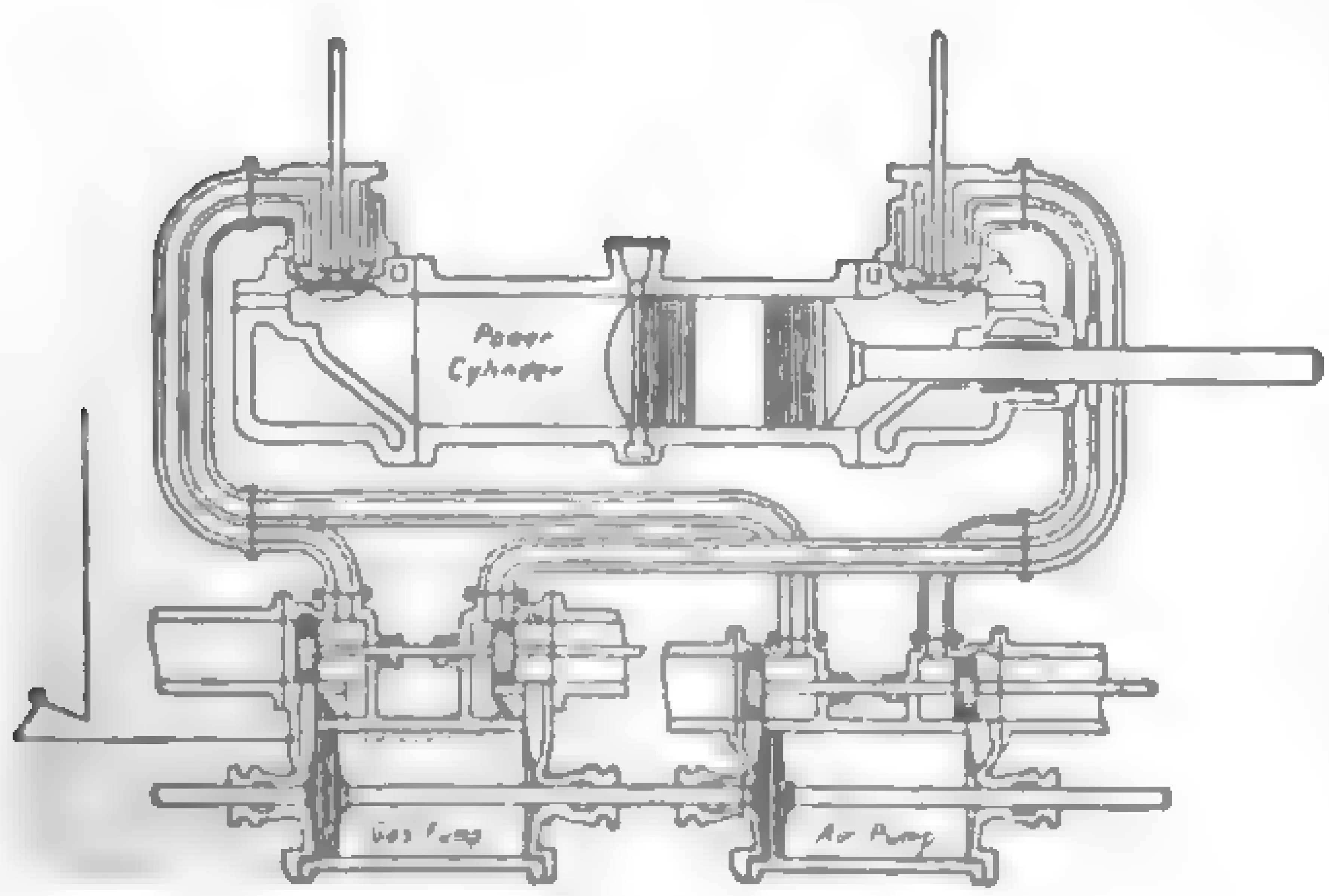


Fig. 6.

Koerting Double-acting Engine.

This two-stroke cycle was really the outcome of some experiments carried out in 1880 by Dugald Clerk, who thought to overcome the four-stroke difficulties by having an explosion for every revolution of the crankshaft. The gas and air are separately compressed to a few pounds per square inch (4 or 5) in the crank case or in a separate engine-driven pump. The exhaust gases pass out by way of a ring of ports which is uncovered by the piston near the end of its stroke. The remaining burnt gases are swept out by a blast of "scavenging" air from the air pump by way of the admission valve, after which the air and gas mixture is admitted, trapped by the returning piston, compressed and fired in the usual way. It will be seen that each end of the cylinder, if double-acting (as is usual in large sizes), is responsible for a power impulse each revolution. The extra complication of the two pumping cylinders is not justified in small engines, so greater detail need not be given here. Still it would be unfair not to state clearly that small two-stroke engines, when properly designed, give excellent results, both for economy of fuel and ease in manipulation. We refer the reader to the companion volume to this on Diesel engines. The two-stroke cycle has been successfully used in connection with all sizes of oil engines.

It is necessary to give a few facts and figures in relation to gas and oil engine fuels, as these engines are machines for converting heat energy which lies latent, or hidden, in the fuel into mechanical energy. The unit of heat in the British system of measurement is the "British thermal unit."

British thermal unit (B.T.U.) is the quantity of heat required to raise the temperature of 1 *lb. of pure water from* 32° *to* 33° *Fahrenheit.*

Calorific value of a gas is the number of B.T.U.'s liberated per cubic foot of gas burned.

In the table on p. 18 those fuels which show a high calorific value give out a great amount of energy per unit weight. Complete combustion means that the full calorific value of the fuel is developed, and gives the maximum pressure in a given size of cylinder. High compression reduces volume and increases rate of flame propagation or increases ease in ignition. The compression should be carried as nearly as practical to the ignition temperature of the gas.

Oxygen of the air combines with hydrogen in the fuel to form water as the product of combustion. Oxygen combines with carbon in the fuel to form carbon monoxide (with insufficient supply of oxygen) and carbon dioxide when completely burned with a plentiful supply of air.

The calorific value of a fuel is determined by means of an instrument known as the calorimeter, in which a sample of the fuel is

burned and the rise in temperature of a known quantity of water observed. From an analysis of the fuel an approximation to its calorific value may be calculated. The quantity of air which would be required to burn a given weight of fuel can also be determined,

Gas.	B.T.U. per cubic foot.	Cubic feet of air required to burn one cubic foot of gas.		Usual compression in pounds per square inch.	Explosion pressure in pounds per square inch.
		Actual.	Theoretical.		
Coal gas . . .	650	9	6	80	285
Producer (anthracite)	140 } 150	$2\frac{1}{4}$	2	160	360
Producer (bituminous)	160 } 150				
Mond gas (water gas).	200	$3\frac{1}{2}$	$2\frac{1}{4}$	—	300
Blast furnace gas .	94	$1\frac{1}{3}$	$\frac{3}{4}$	170	225
Acetylene . .	1,560	20	$12\frac{1}{2}$	70	—
Gasoline vapour .	520	—	—	70	350
Kerosene vapour .	(liquid)	—	—	70	300
Coke oven gas . .	520	$7\frac{1}{2}$	$5\frac{1}{2}$	60	—
Alcohol . . .	(liquid)	—	—	180	—

since it is known that air contains 1 part by volume of oxygen, the supporter of combustion, to 3·77 parts of nitrogen. When we come to consider producer gas this subject will be reviewed more fully.

There are one or two terms which the attendant would be better to know before proceeding to consider engine details. One of these is "density." This is the mass per unit volume, and is obtained by dividing a given mass (which for practical purposes may be taken as the weight) of the substance by its volume. The density so found is the "absolute density" of the substance. In practice, the "relative density" or "specific gravity" of a substance is more frequently specified, this being the density of the substance relative to that of some standard substance, and generally expressed as the ratio of the density of the substance to that of the standard. For solids and liquids the density of water is taken as the standard, and for gases the hydrogen standard is employed. For example, if a cubic foot of steel weighs 490 lb. and a cubic foot of water weighs $62\frac{1}{2}$ lb., the specific gravity of the steel is obtained by dividing 490 by $62\frac{1}{2}$, and this gives 7·8 as the required figure. Similarly, if a cubic foot of coal gas weighs 0·0354 lb. and a cubic foot of hydrogen weighs

0·0056 lb. under the same conditions, the specific gravity of the coal gas will be obtained as follows:

$$\text{Specific gravity of coal gas (relative to hydrogen)} = \frac{\cdot 0354}{\cdot 0056} = 6\cdot 3.$$

The specific gravity of coal gas relative to water would be ·0354 ÷ 62·5, that is, ·00057. This great difference in density between coal gas and water will at once make it obvious to the reader why it is that water is used as a seal to prevent the escape of coal gas from its containing tank.

We now come to the definition of work and power. An engine or any other mechanism is said to perform work when it overcomes an opposing force through any distance. By multiplying the numerical value of the force by the distance through which it has been overcome we get a measure in corresponding units of the work done. If we take the *pound* as our unit of force and the *foot* as the unit of length we get the *foot-pound* as our unit of work. For example, if a wagon weighing 12 tons is moved along a level line of rails for a distance of 100 ft. and the friction amounts to 12 lb. per ton, then we should arrive at the work done as follows:

Resistance to motion = (12 × 12) lb. = 144 lb.
Distance travelled by wagon = 100 ft.
∴ Work done = (144 × 100) foot-lb. = 14,400 ft.-lb.

It should be noted that no work is done until the applied force is sufficient to move the wagon.

Power is taken to be the *rate* at which work is done, and we say that an engine is developing 1 *horse-power* (1 H.P.) when it is performing 33,000 ft.-lb. of work per minute. Thus, if any engine performs, say, 990,000 ft.-lb. of work in five minutes, the average work done per minute would be (990,000 ÷ 5) ft.-lb. = 198,000 ft.-lb., and the average horse-power developed during the period would be (198,000 ÷ 33,000) H.P. = 6 H.P.

Efficiency.—A certain amount of power is lost in all machines on account of friction, air resistance, etc. For this reason more power is always required to drive, say, an engine than is delivered by the engine at the pulley. The ratio of the output power to the power at the piston (or the ratio of the output to the input power) is termed the efficiency, and it may be expressed as a fraction or as a percentage.

Let P = average effective value of the pressure on the piston during each cycle of operations (pounds per square inch).
A = area of piston (square inches).
L = Length of stroke (feet).
N = Number of *working* strokes per minute,

then the work done per minute in the cylinder equals $P \times L \times A \times N$ ft.-lb., and the horse-power developed in the cylinder or the *indicated* horse-power (I.H.P.) will be given by $\dfrac{P \times L \times A \times N}{33{,}000}$.

As already noted, the whole of this power is not transmitted by the pulley on account of losses in the engine. The horse-power actually delivered at the pulley, which may be measured by a braking arrangement on the pulley, is termed the *brake* horse-power (B.H.P.).

Thus the efficiency of the engine $= \dfrac{\text{B.H.P.}}{\text{I.H.P.}}$, giving a fraction, or $\dfrac{\text{B.H.P.}}{\text{I.H.P.}} \times 100$, giving a percentage.

As an example, let us take the case of an oil engine developing 14 B.H.P. and giving an I.H.P. of 20.

$$\text{Efficiency} = \frac{14}{20} = 0{\cdot}7,$$

or

$$\text{Efficiency} = \frac{14}{20} \times 100 = 70 \text{ per cent.}$$

The engine will therefore deliver seven-tenths or 70 per cent. of the power developed in the cylinder.

CHAPTER II

ENGINE DETAILS

All types of engines, whether using gas or oil fuel, when first installed require special care and attention during their first period of use. The lives of piston rings and bearings are very much affected by the first two or three days' running. It is very much to the advantage of the operating man, if occasion permits, to watch closely the details of construction when the engine and plant are being assembled, in

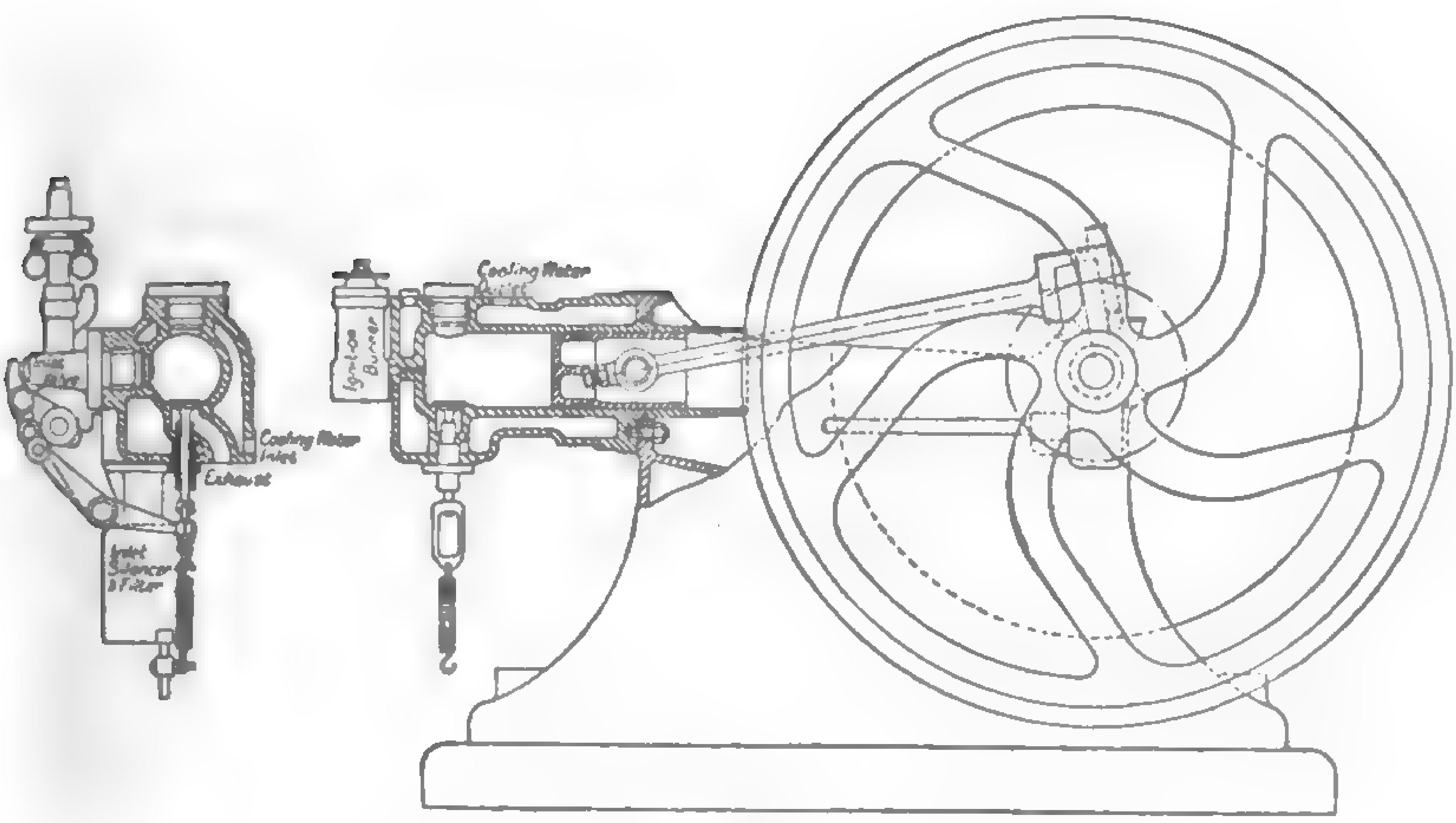


Fig. 7.

5 H.P. Crossley Gas Engine (Overhung Cylinder).

order to familiarise himself with them as much as possible. By so doing a better understanding of the mechanical construction results, which is a valuable asset to correct operation.

It is here proposed to study the several parts of the engine in order to understand their detailed construction, and at the same time the method of oiling the working parts may receive considera-

tion. The main details of the internal combustion engine will be found to be very much heavier than those of a steam engine of the same power. The former have been designed to receive the sudden shocks due to the method of working.

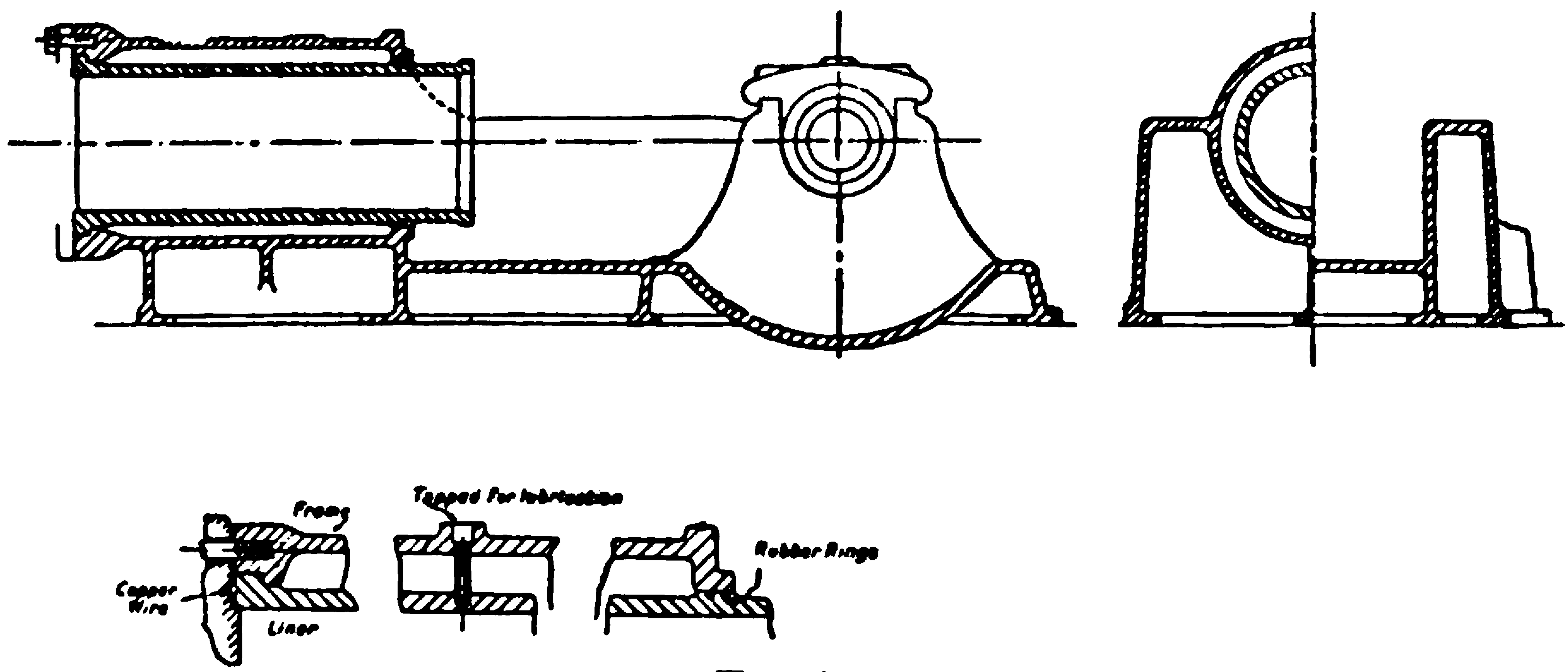


FIG. 8.
ENGINE FRAME AND LINER.

Gas engines can now be made to work very noiselessly, and to allow every detail to be easy of access and quickly dismantled

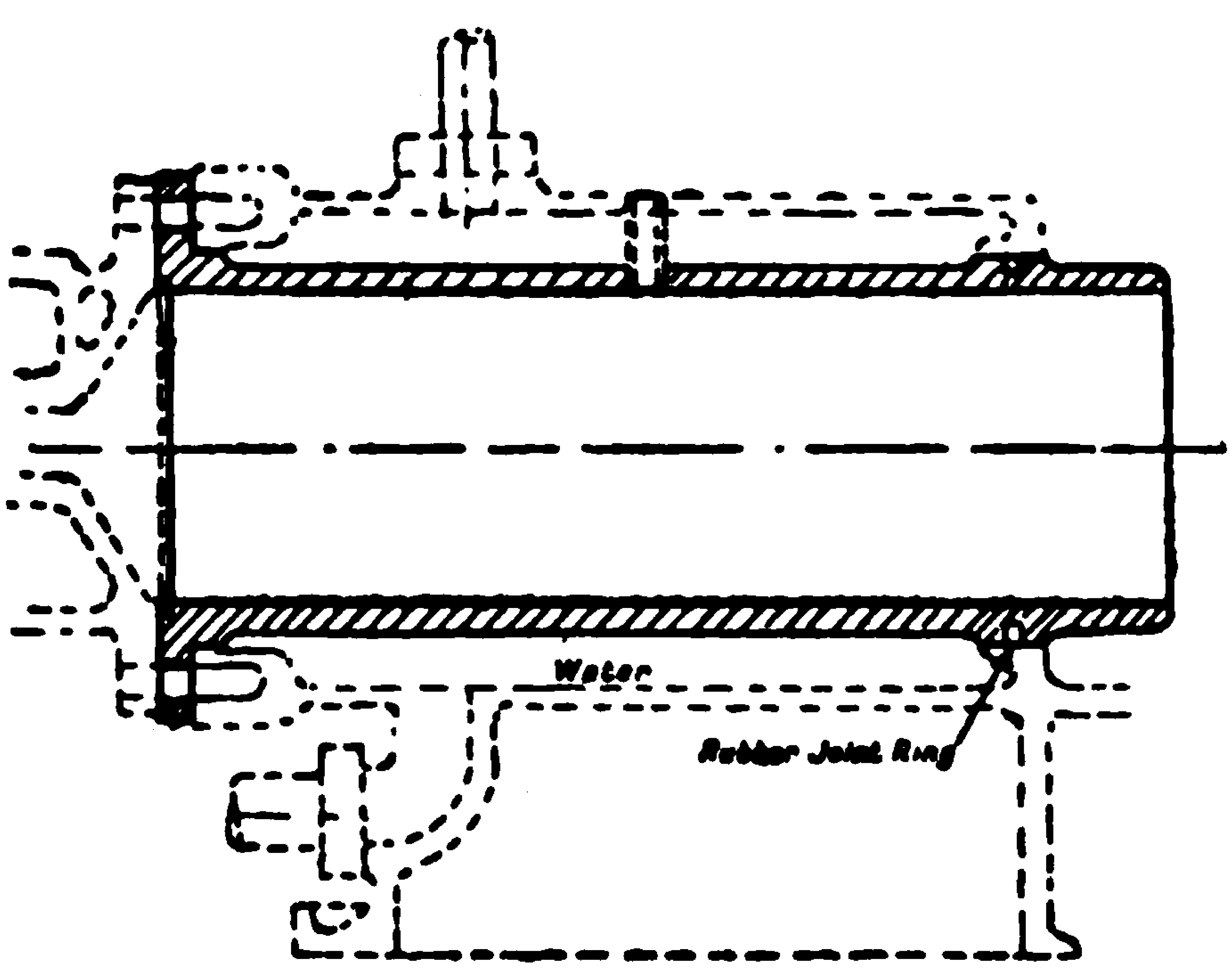


FIG. 9.
LINER.

and put together again after cleaning and repair. The operator should see that no part of his engine is destroyed, even in appearance, while under repair. Each part is made to be withdrawn and

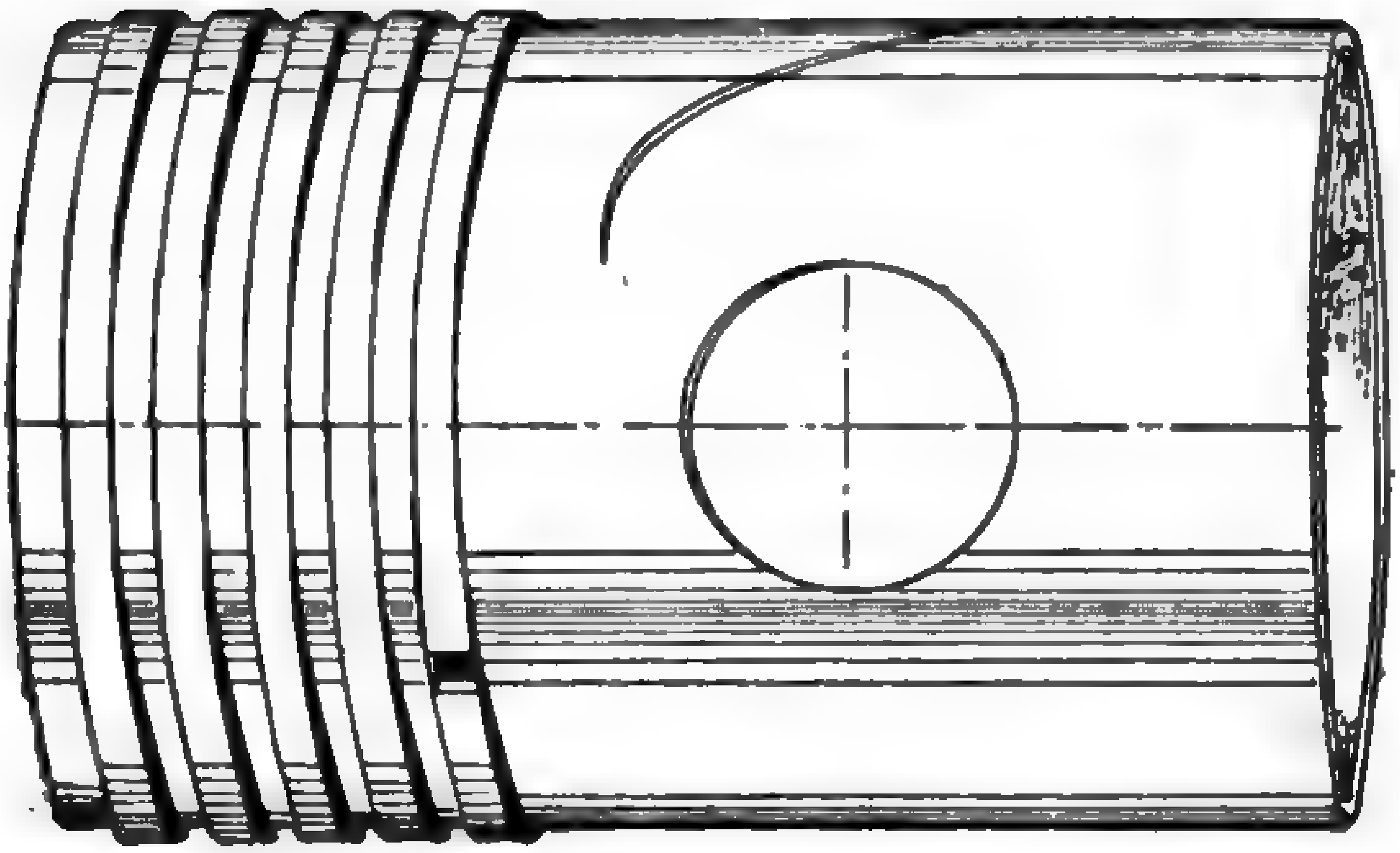


FIG. 10.

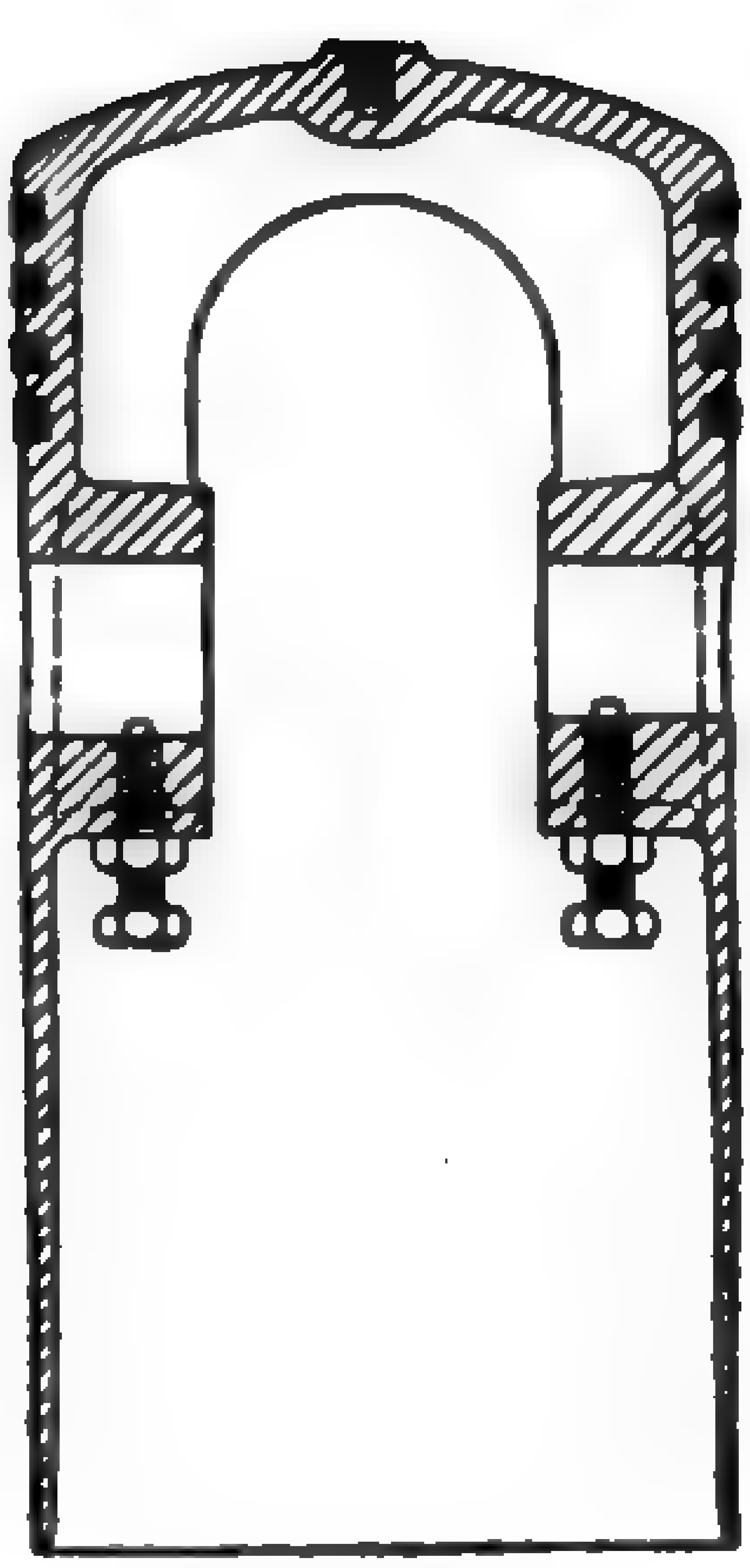


FIG. 11.

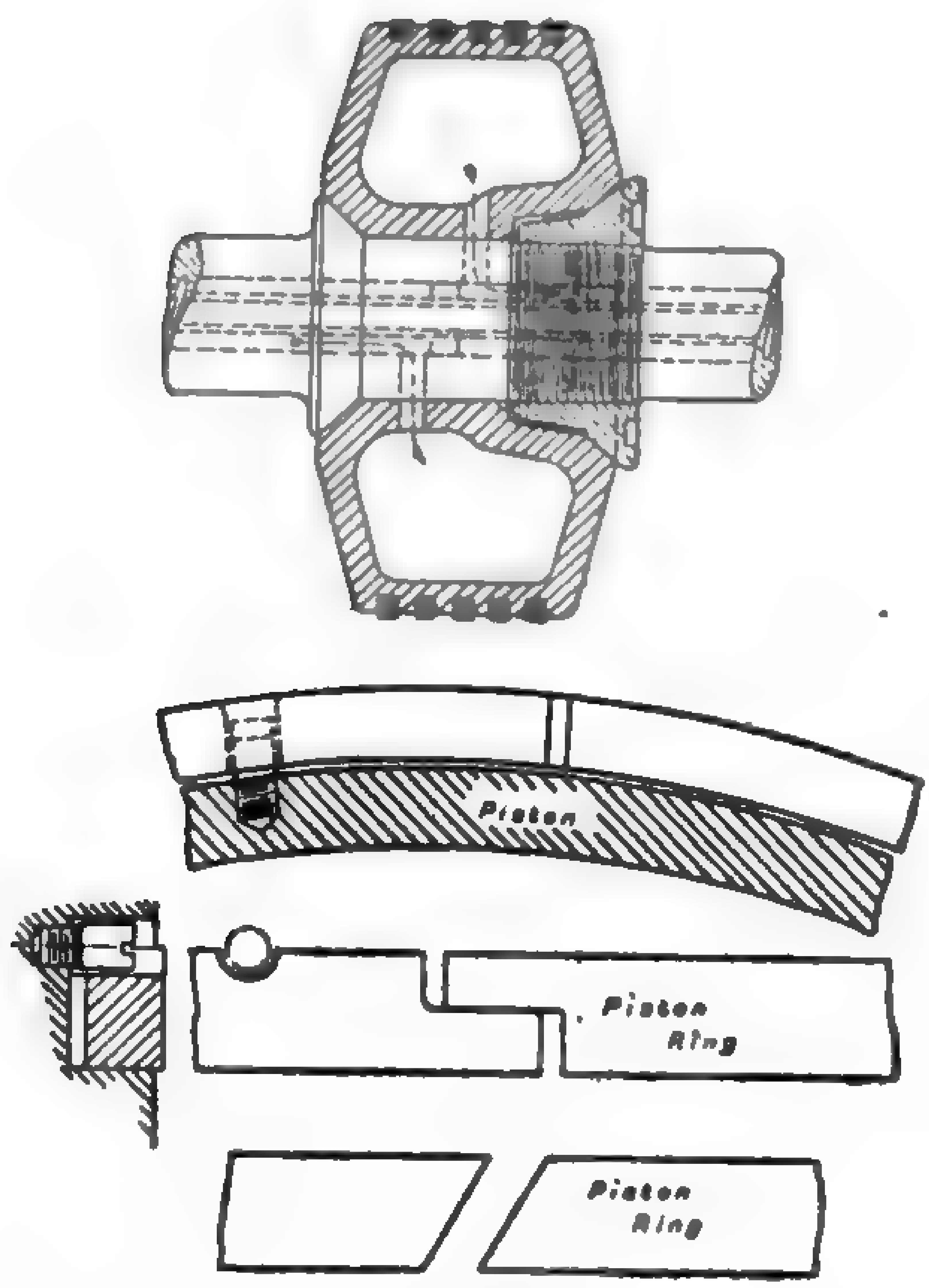


FIG. 12.

PISTONS.

replaced in a certain definite manner, and before an engine leaves the maker's works the several parts are typed.

The engine bed for a horizontal gas engine is usually made from

the mammoth frame pattern which extends to the back of the cylinder. In this way the cylinder is supported for its whole length. Some of the smallest engines had the cylinder hung from the back of the frame (Fig. 7), but this does not make for steadiness of working. On most of the frames provision is made for catching any waste oil. Grooves provided for this purpose must be kept clean and free from particles of cotton waste ; neglect of this may lead to damage of the concrete foundations. The engine frame is grouted, both inside and outside, to the concrete foundation. For engines with cylinders from 10 in. to 24 in. in diameter there are usually eight holding-down bolts, and their diameter may be one-sixteenth of diameter of cylinder plus $\frac{1}{4}$ in. Thus the frame of a 16-in. cylinder engine would be held down by eight bolts, each of $1\frac{1}{4}$ in. diameter. Fig. 8 shows a frame with

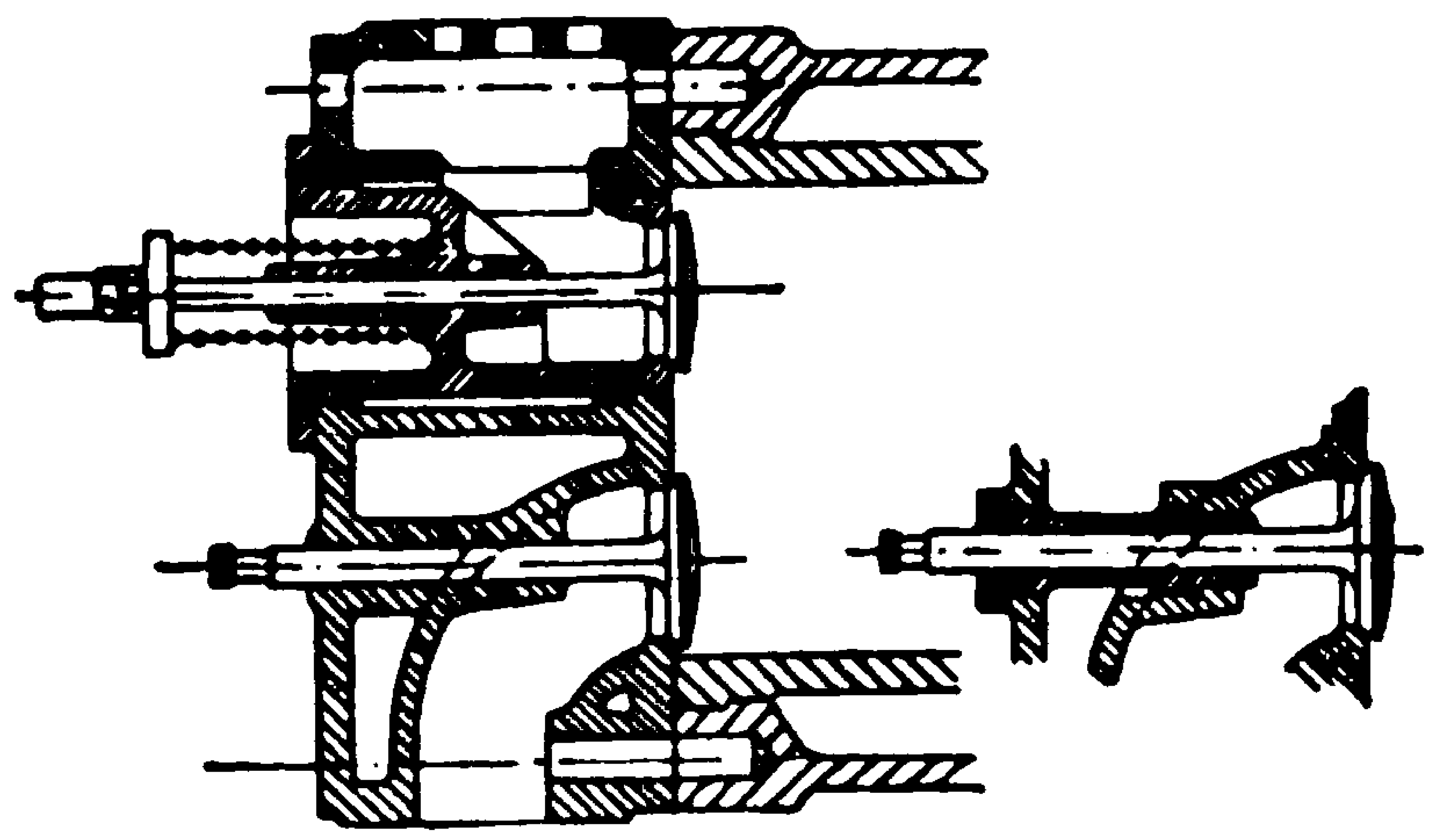


FIG. 13.
CYLINDER COVER.

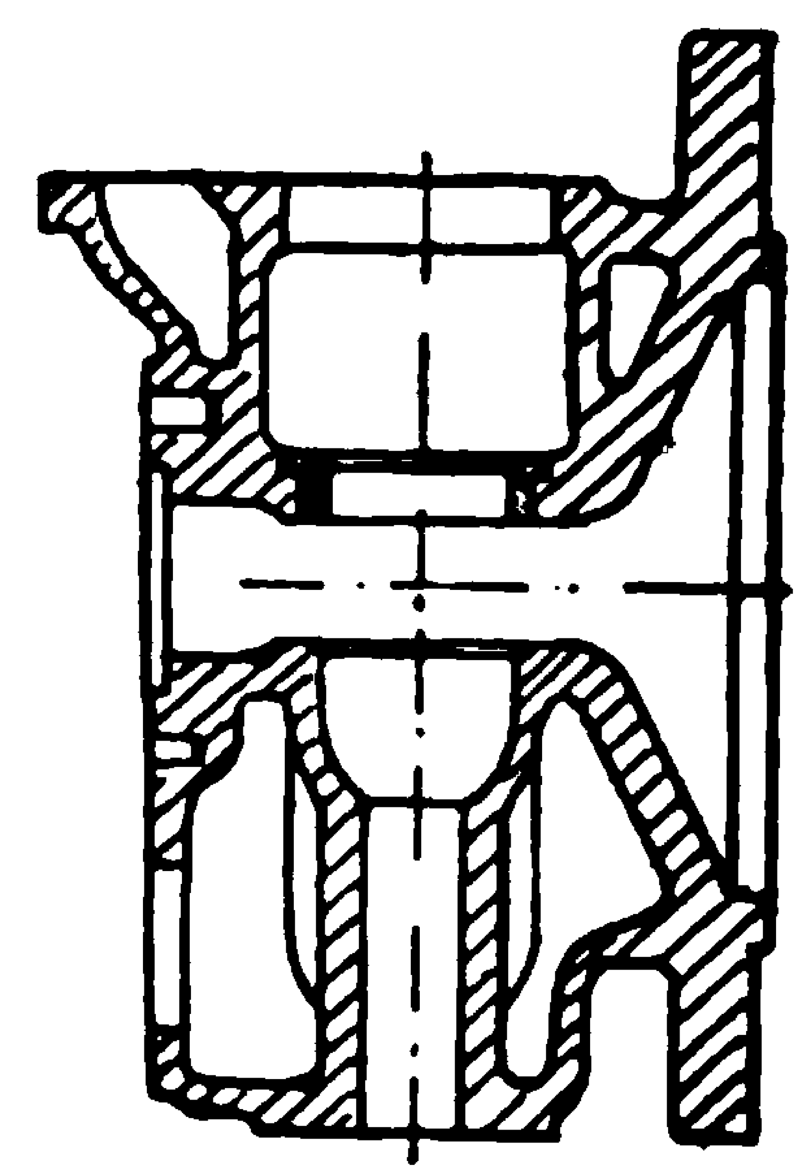


FIG. 14.
CYLINDER COVER.

cylinder liner and main bearing. The small details show how the frame has been recessed to receive the liner. On the face of the recessed part two or three small grooves have been turned, and at the breech end of the frame there are grooves to receive rubber rings, thus ensuring a watertight joint between the cylinder water-jacket and the inside of the liner.

The cylinder liner will be seen to consist of a simple casting. It is made of specially clean and hard cast iron. The method of fixing is made clear in Fig. 9. No fixing studs are required, and it will be seen that, although made watertight, the liner is free to expand longitudinally. In the case of the two-stroke engine, all ports should be made straight and as free from changes in thickness of metal as possible.

The piston is made of the same close-grained hard cast iron as the cylinder liner. It is of considerable length and is fitted with four to

seven spring rings. The larger number of rings ensures a better bearing surface, and, as the bearing pressure is thus lower per square inch, lubrication is more nearly perfect. See that an oil groove has been milled or cut in the plain part of the piston, as this helps to spread the lubricant. Figs. 10 and 11 show the method of fixing the gudgeon pin. This pin is made of hardened steel. There are only small differences between pistons for use in gas engines and those intended for oil engines, and probably those differences will be noticed by studying the general arrangement of engines shown throughout this book. Built-up pistons with junk rings are preferred for engines with cylinders over 20 in. in diameter.

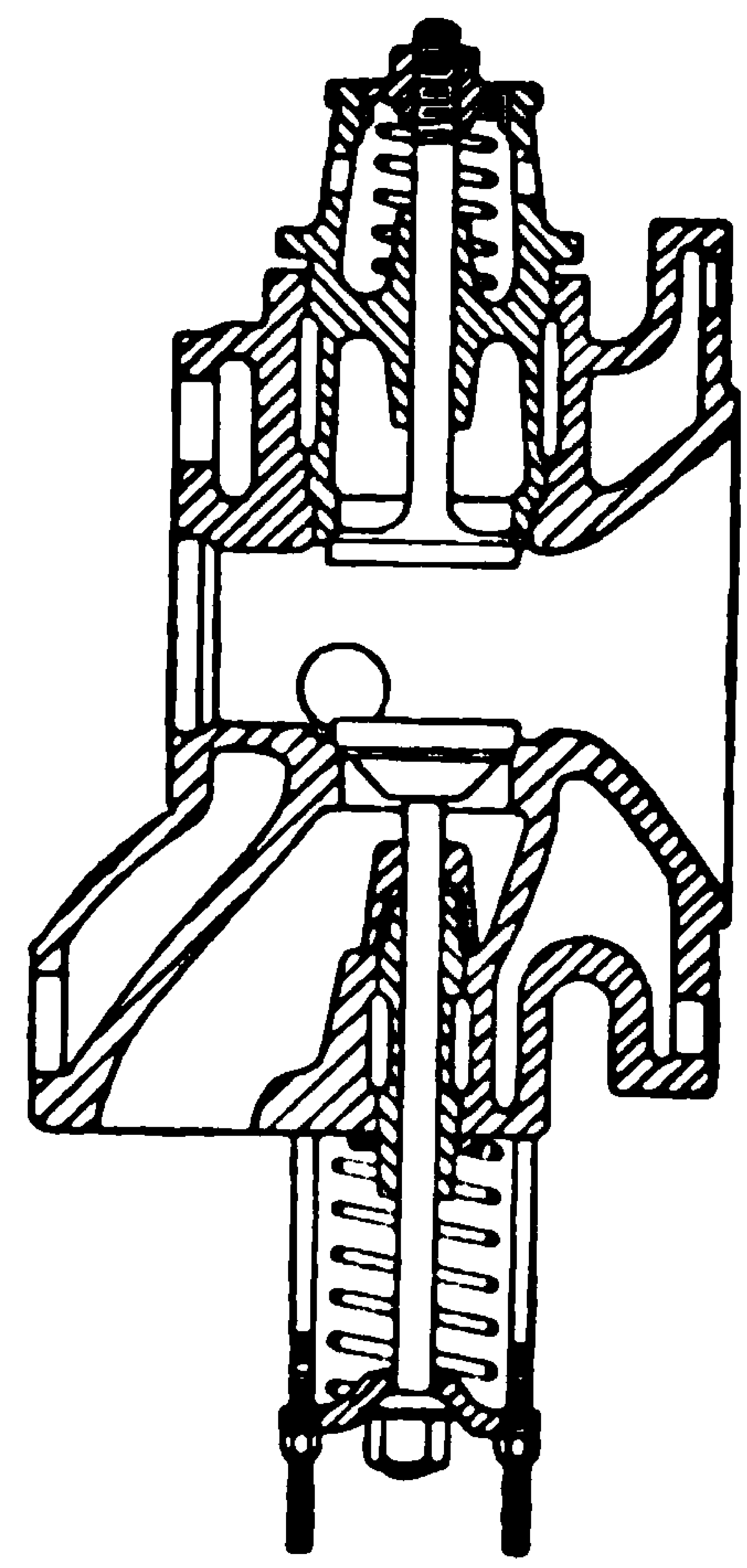


FIG. 15.
CYLINDER COVER FOR OIL ENGINE.

Piston rings are made by turning pieces from a hard-grained cast-iron pipe. A common rule when replacing a piston ring is to make the new ring $\frac{1}{32}$ in. per inch diameter of cylinder larger in diameter than the cylinder, and then cut 3·14 times the difference in diameters out of the ring to allow it to spring into the cylinder.

The cylinder cover or breech end is one of the most important parts of a gas or oil engine. In design it is rather a complicated portion, and great care must be taken in the casting to see that all ports and passages are clear, that all cores have been removed, and that the cores have not shifted during casting. This is more the work of the engine builder than of the operator, but he must be warned that all engines are not perfect. In recent years the design of breech ends has received much attention, and they do not now give the attendant so much worry. Small covers are fitted for inspection of valves, and larger doors for the removal of any sediment which has been dropped from the

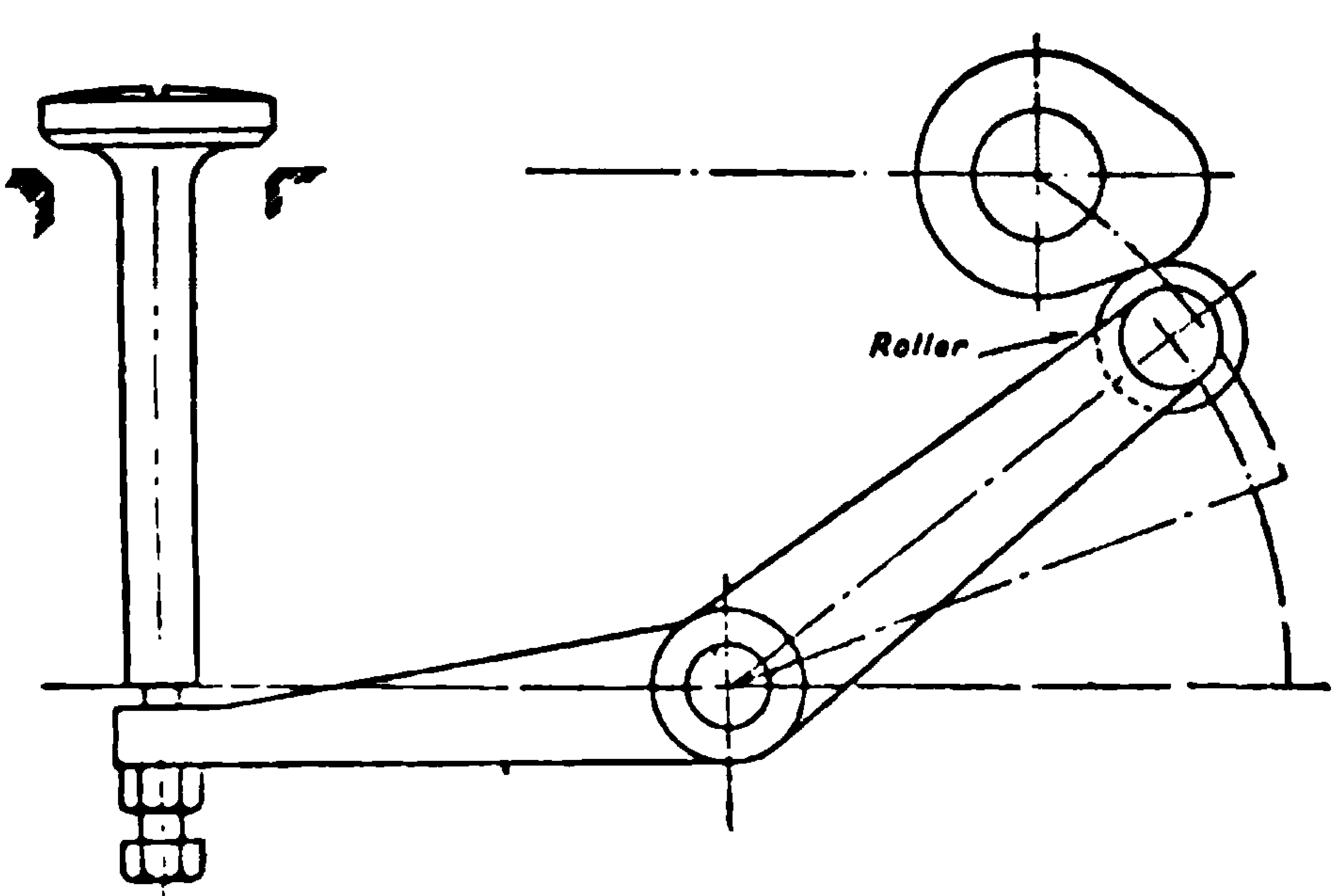


FIG. 16.
EXHAUST VALVE, LEVER AND CAM.

cooling water. Porous cylinders and covers may give the attendant much trouble. These covers should be tested by a water pressure of at least 80 lb. per square inch. In a few cases rusting with a solution of sal-ammoniac or brine has made a comparative

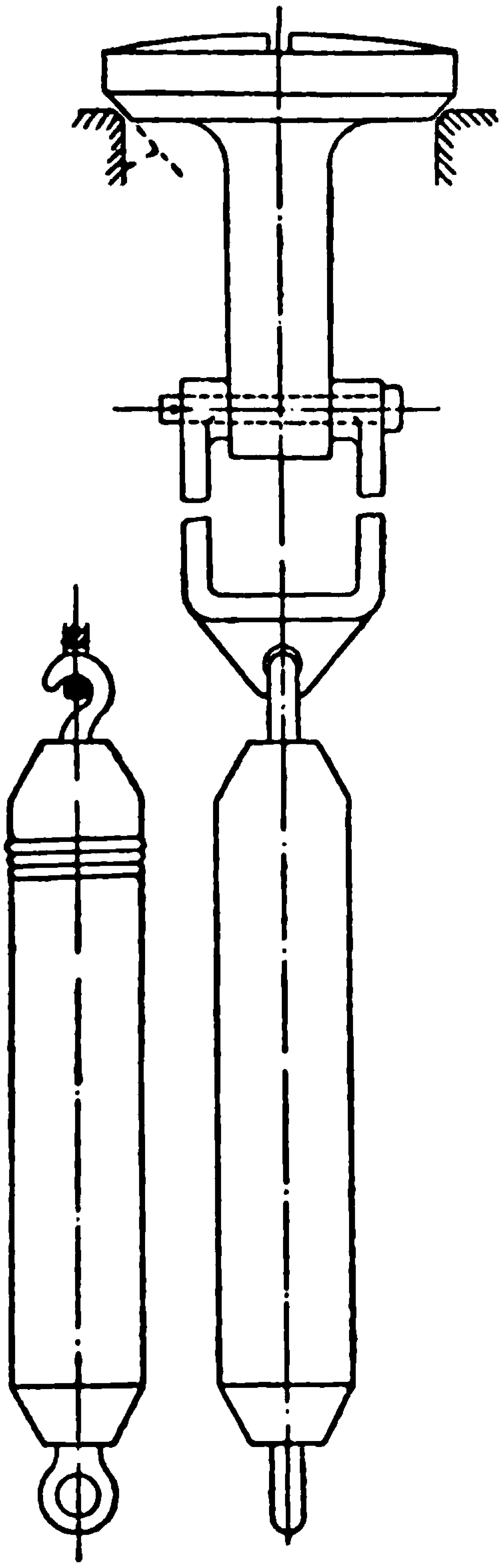


FIG. 17.
EXHAUST VALVE WITH STIRRUP, ETC.

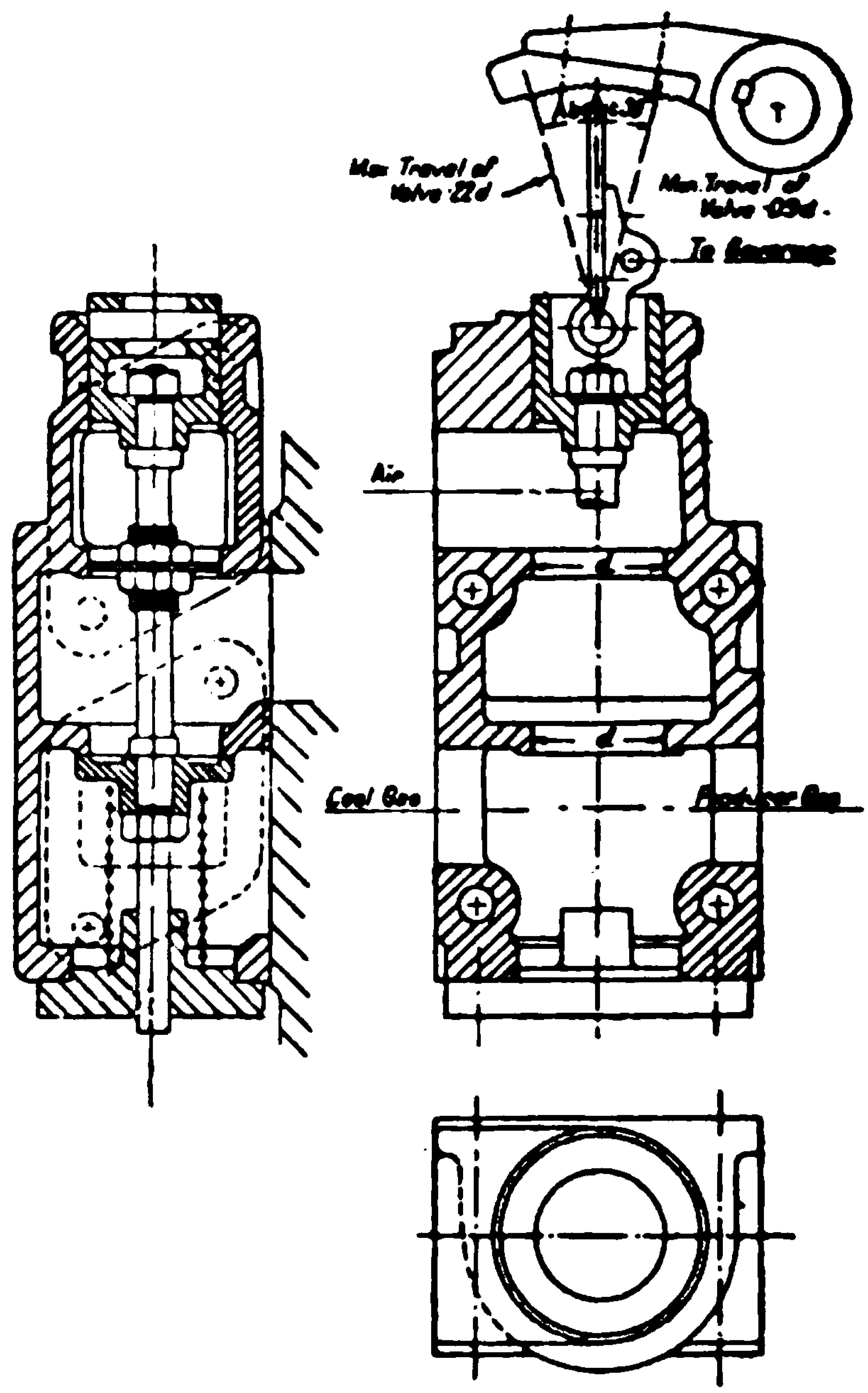


FIG. 18.
GAS AND AIR VALVE.

difference in the amount of cooling water which found its way into exhaust valve chamber and cylinder. This rusting up is only a makeshift, and, if the casting is not perfectly sound, weeping of the jacket water can hardly be avoided at the high cylinder temperature. The cylinder cover for a horizontal gas engine is shown in Figs. 13 and 14. The clearance space between the piston,

when at the extreme inner end of its stroke, and the valves is called the "combustion chamber"; and it is into this space that the gas is compressed ready for ignition. Should a new cylinder cover joint be required to be made, the surfaces of the cylinder and of the breech end must be carefully cleaned and all parts of the old joint adhering to them removed. The surfaces are best cleaned of grease and the joint coated over with tallow and graphite. When the engine has been running some time, the stud nuts should, while hot, be thoroughly tightened up.

The cover for an oil engine is very similar to that of the gas engine. This cover is shown in Fig. 15 and will be explained in conjunction with the sketches of the complete oil engine. It will be noticed that

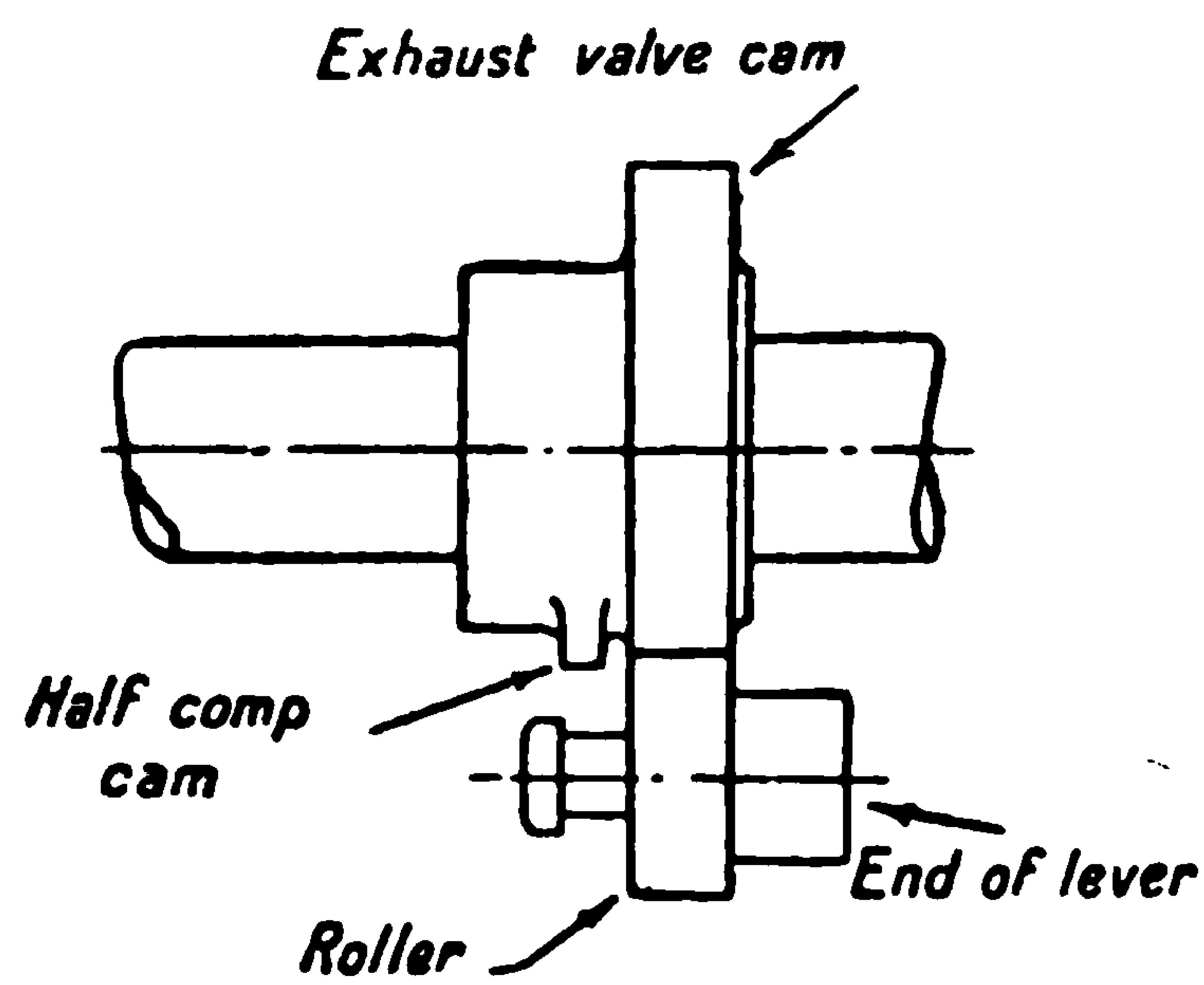


FIG. 19.
HALF COMPRESSION CAM (PLAN).

the admission valve seat is large enough to allow the exhaust valve to pass through it, and also that there is an adjustment provided for the exhaust valve spring.

Gas and oil valves are, as a rule, made of mushroom pattern, either conical or flat faced. When on the suction stroke of the engine the inlet valve opens by being drawn from its seat on account of the pressure inside the cylinder falling below atmospheric, the valve is said to be automatic. On the other hand, when the valve is opened by means of a cam acting on the valve tappet, the valve becomes mechanically operated. Sleeve piston valves, rotating or sliding, are sometimes used, but these have a much greater rubbing surface than the mushroom valves. Fig. 16 shows an exhaust valve, valve lever, and cam. The camshaft in the four-stroke cycle engine runs at half the speed of the engine crankshaft. A valve, valve seat, valve stirrup, and spring are illustrated in Fig. 17. In this case

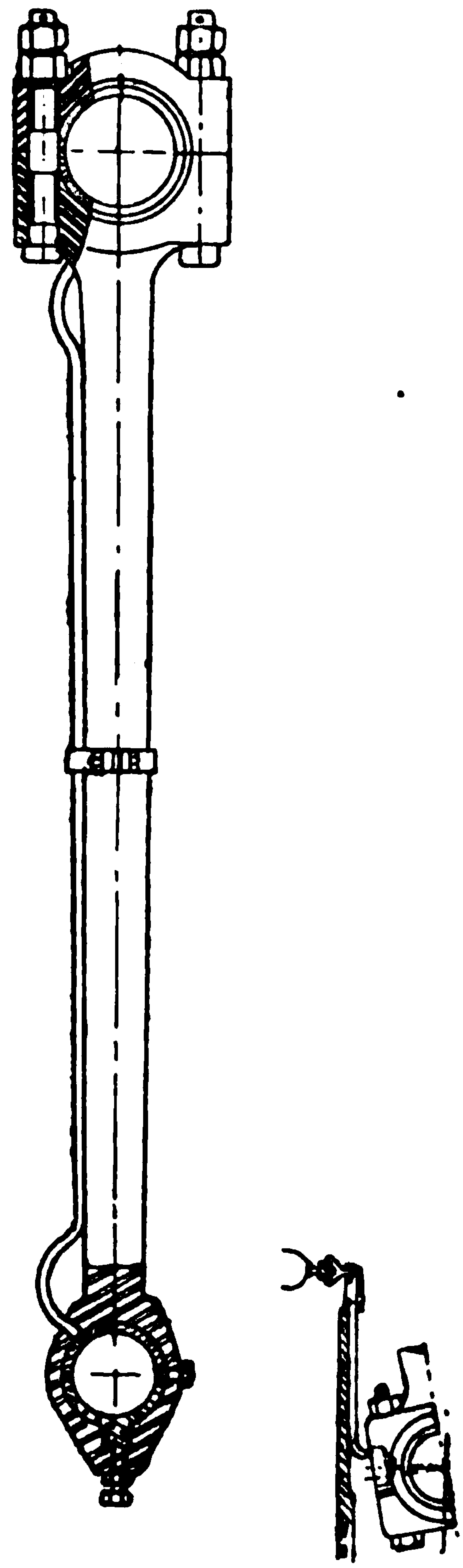


Fig. 20.
Connecting Rod.

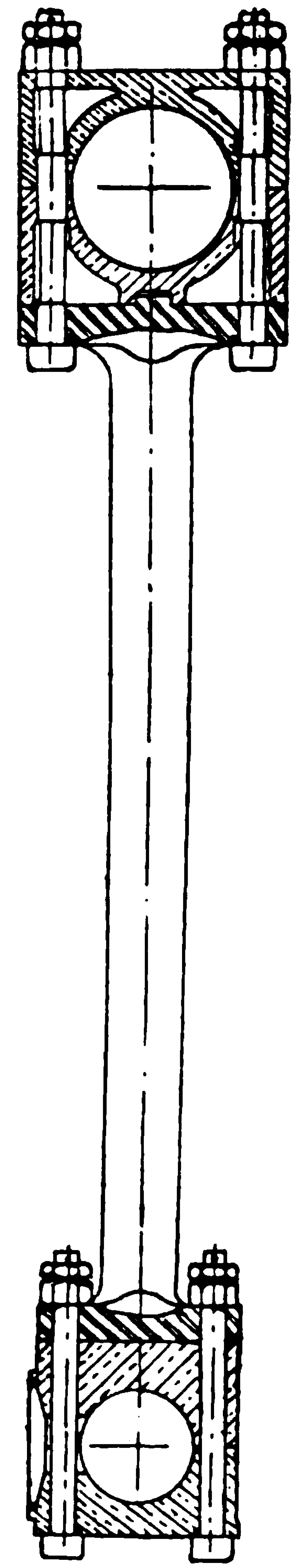


Fig. 21.
Connecting Rod.

the spring tension cannot be altered as in Fig. 15. A gas and air valve is shown in Fig. 18. This diagram also shows how the governor lever is connected to the inlet valve, thus acting as a throttle governor. The attendant might here be well advised to look at the position of the inlet and the exhaust valves. He will notice that the exhaust

valve is subjected to a very high temperature, say 400° to 600° C. In large engines the temperature of the cover is always reduced by water cooling. Injection water has been tried, but has not proved

FIG. 22.
PICTORIAL SKETCH OF CRANKSHAFT (LIGHT FLYWHEEL).

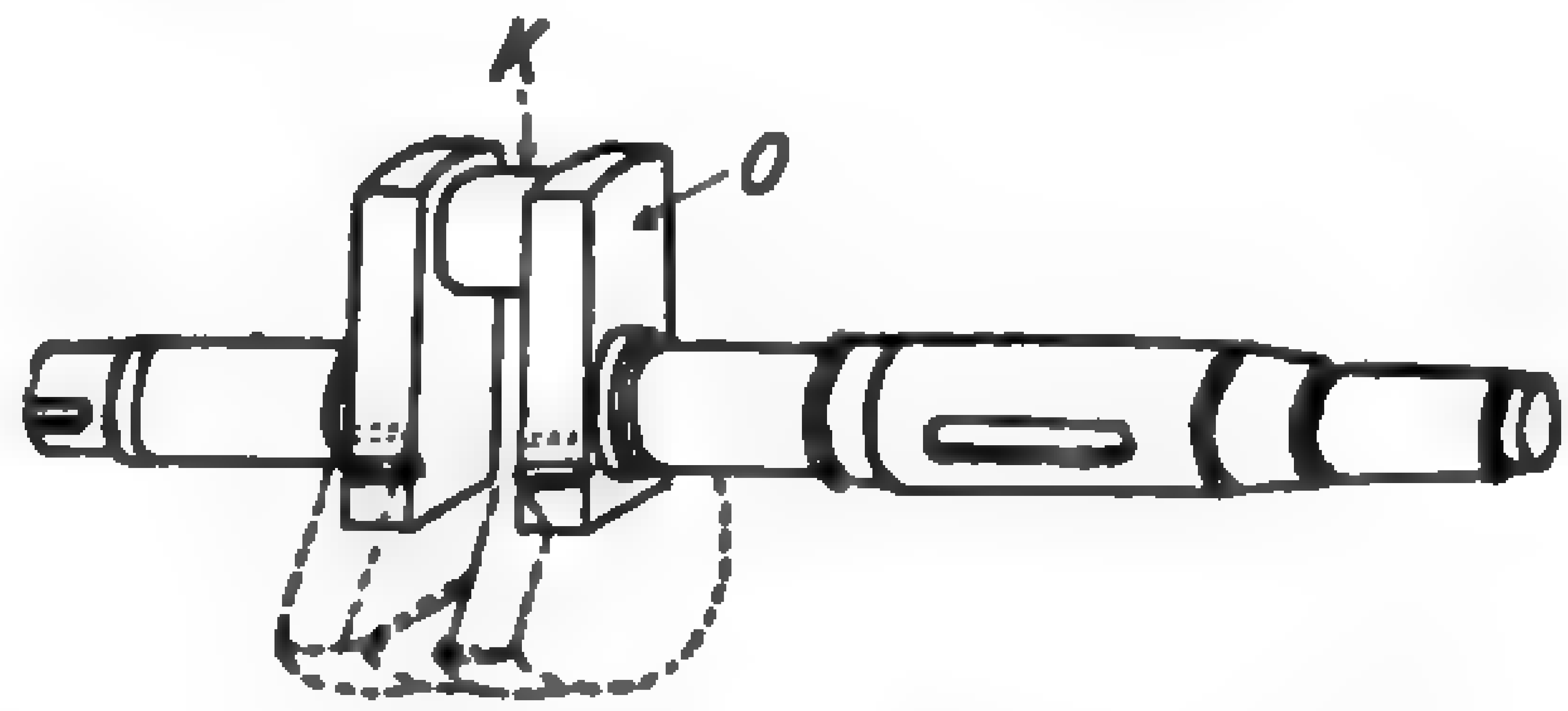


FIG. 23.
PICTORIAL SKETCH OF CRANKSHAFT (THREE BEARING).

successful, as steam was generated and gave rise to considerable difficulties. Valve stems have been made separate from the cone part, and these stems are sometimes made of nickel steel. When

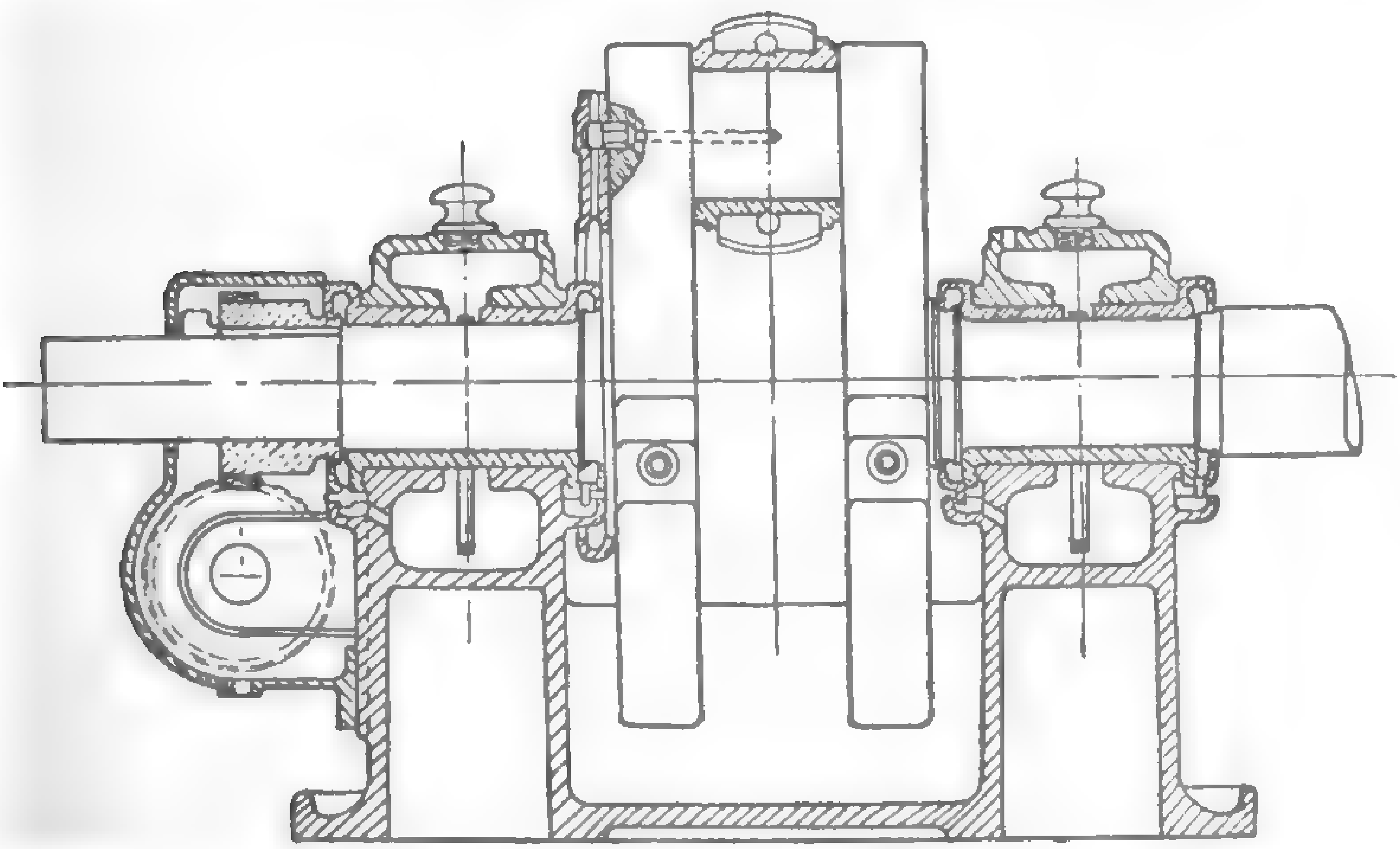


FIG. 24.
END VIEW, SHOWING ENGINE SHAFT AND BEARING.

cast with the valve they are usually heavy, sometimes as much as a quarter of the diameter of the valve. The end of the stem or tappet is made spherical, and in some cases flat. On the latter there is a considerable amount of bending action, which necessitates a much

larger diameter. In large engines the valves require to be balanced. Exhaust valve and seat troubles will be dealt with later, as these

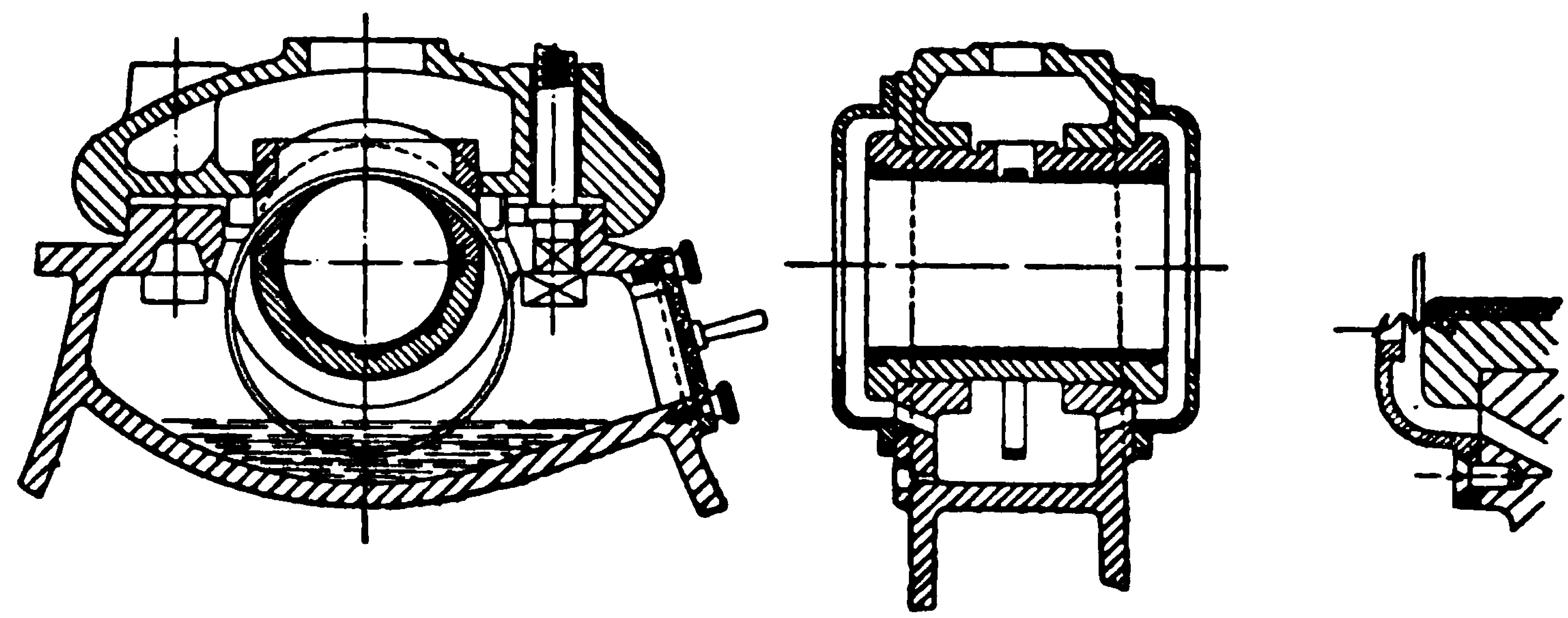


FIG. 25.
RING BEARING.

often cause the attendant much worry and anxiety. A plan view of the cam working the exhaust valve is shown in Fig. 19, and this cam

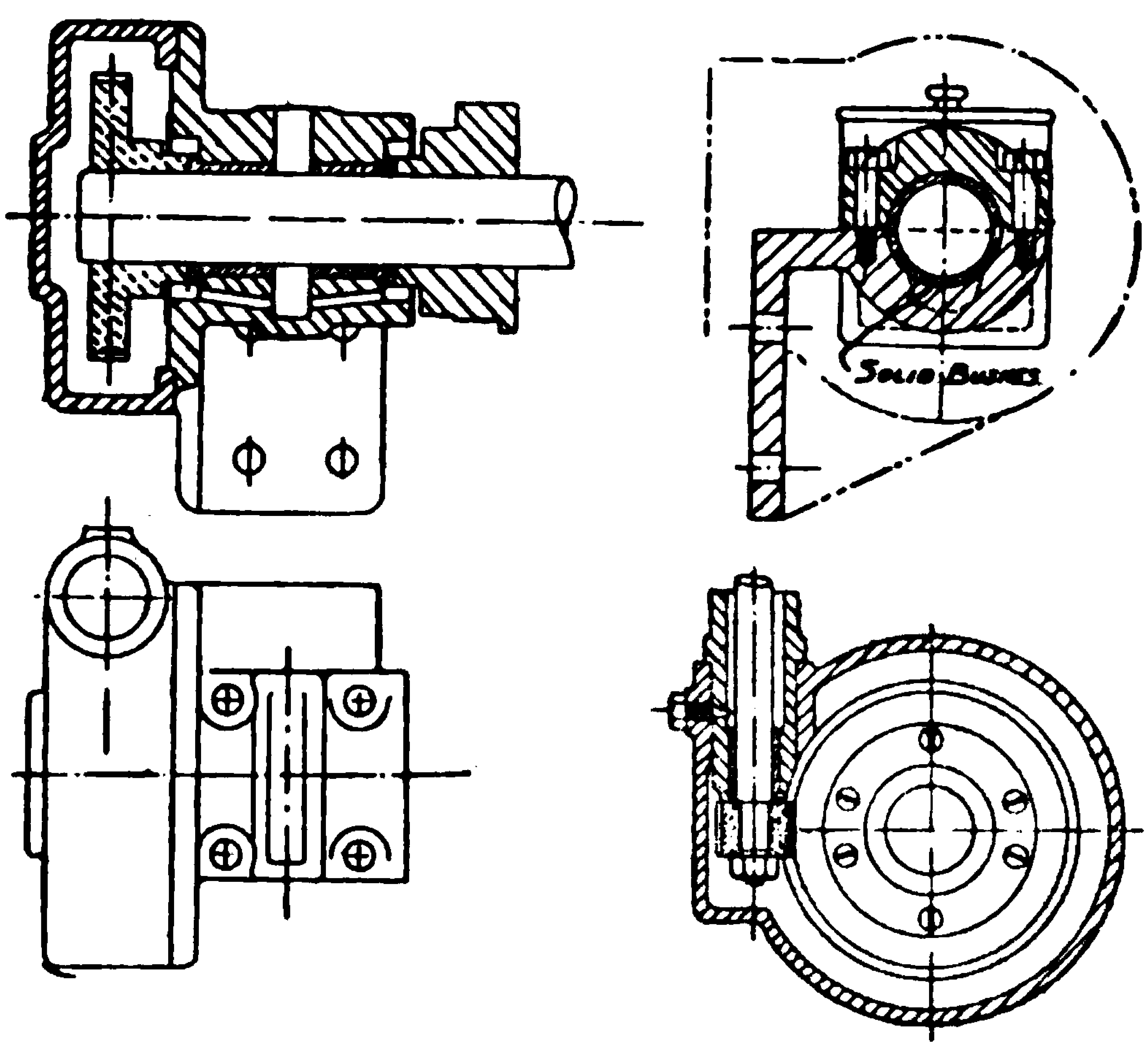


FIG 26.
BACK BEARING (LAYSHAFT).

has a half-compression cam cast on the same boss and fixed to the lay or side shaft. Note how provision is left on the roller pin to allow the roller to come in contact with the half-compression cam.

Gas and oil engine connecting rods are fitted with half brasses and a loose adjustable cap or keep similar to the big end of a marine engine connecting rod. The small or piston end has sometimes a cap and sometimes a solid forged end fitted with adjusting pin. The

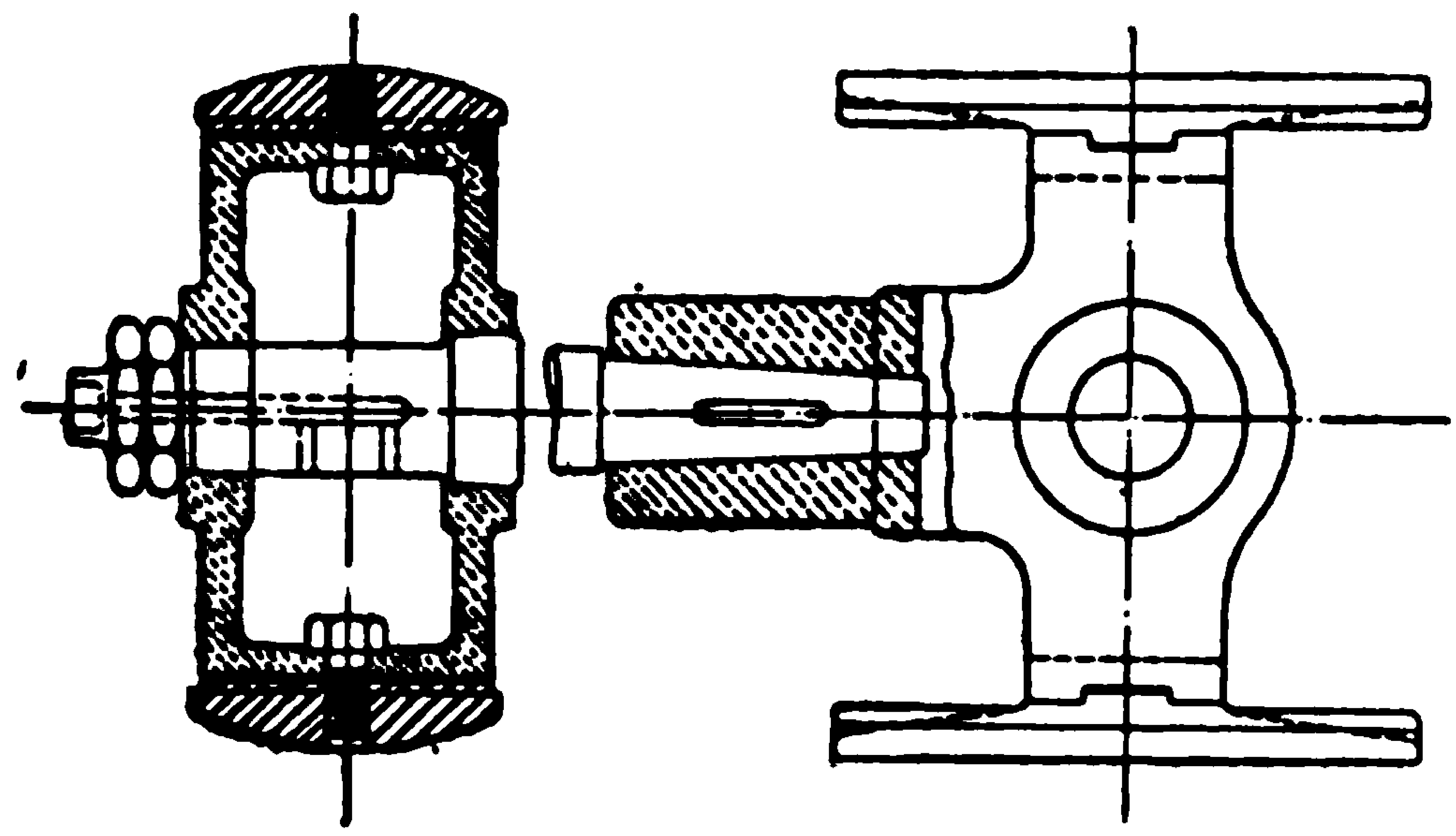


FIG. 27.
CROSSHEADS.

two forms of the small end are shown in Figs. 20 and 21. Mild steel is the usual material used for the connecting rod, which is machined and polished all over. The crankpin end has gun-metal bushes, and is often lined with white metal, while the piston end bushes are

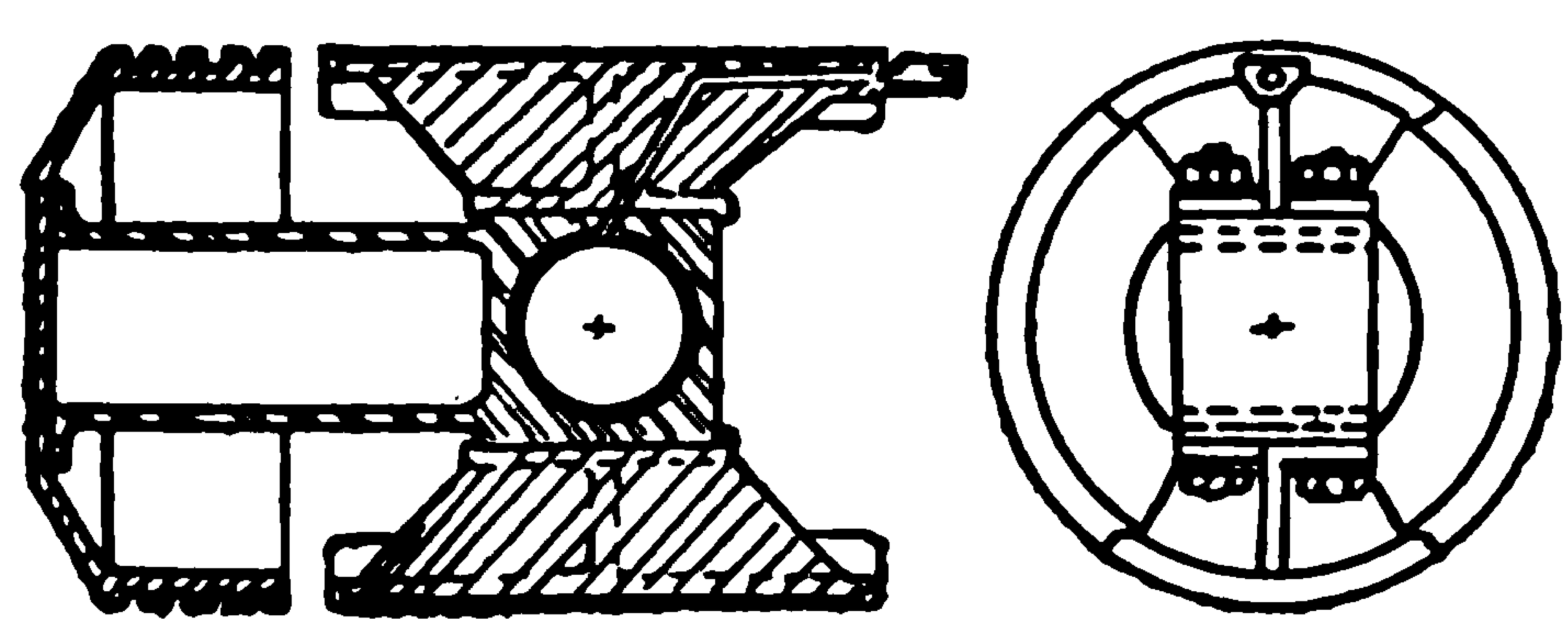


FIG. 28.
PISTON AND CROSSHEAD COMBINED.

usually made of phosphor-bronze. Engine builders are very particular to make the piston and crank pins of ample size to reduce bearing pressures, and on the perfect lubrication of these much of the success of the engine depends. Cap bolts and adjusting screws should have good locking arrangements. A connecting rod is usually from five to six times the length of the crank. The attendant should consider the effect of taking up the brasses after wear. This shortens the rod or the distance between the pin centres. In

the case of the trunk engine this does very little harm, and only increases the clearance volume at the end of compression.

The crankshaft of the gas and oil engine is much heavier than that of a steam engine of equal power. It is usually made of Siemens-Martin open-hearth steel, forged in one piece, even up to four cylinders in the case of the oil engine, and machined all over. In the case of the oil engine the flywheel is now bolted to flanges, solid, or keyed on to the crankshaft. The flange coupling bolts must be strong enough to carry the mean twisting moment, and also the twist due to the flywheel having to store the excess energy of the ignition stroke. The pictorial sketch, Fig. 22, shows a small engine crankshaft with light flywheel. This might be suitable for the Crossley 5-B.H.P. engine shown in Fig. 7. The lower sketch, Fig. 23, is a three-bearing crankshaft with one flywheel. Balance weights are shown by dotted lines; they are fastened to crank webs which are rectangular in shape. A hole, of such a depth as to pass the middle of the length of the crankpin, is bored through the crank web at the point *O*; at right angles to this, and at point *K*, another hole is bored in the pin to meet the first one. Thus a pipe with a right-angled bend is formed and is utilised to lubricate the pin. Fig. 24 shows a crankshaft and main bearings for an oil engine. The attendant should note the method of lubrication.

Crankshaft bearings in gas and oil engines are made large in diameter and from one and half to one and three-quarter times the diameter in length. Smaller engines are usually built with two bearings, which are placed very close up to the crank webs. Some bearings are made to take up wear in two directions and have the brasses in four parts; others have a top and bottom brass. An oil box is cast on the cover, and the bearings may be self-lubricating with one or two loose oiling rings, as in Fig. 25, or they may have a fixed oiling ring and wiper. Attendants have found that even when the boxes are filled with oil the bearings heat up between the oil rings. This heating up is difficult to account for, and engineers differ in their reasons as to the cause. The difficulty is got over by boring a small hole in the bottom brass, midway between the rings, which allows the oil to escape from the middle of the journal. All oiling rings are made in two parts dovetailed into each other and held together by means of grub screws. They are often made circular on the inside, so that they may easily sway or rock on the bearing.

The outside bearing in the three-bearing crankshaft is similar in detail to the main bearings. Bearings up to 4½ in. in diameter have no white-metal lining, but above this size the brasses are lined with white-metal, cast iron or cast steel forming the frame. To prevent

waste of oil a guard is fitted to the sides of the bearing as shown (Fig. 25). The oil from the trough returns to the reservoir below the bearing. This figure also shows the best way of arranging the white-metal. The white-metal is not allowed to project so as to touch the crank web or oil fender ring. Projecting white-metal is easily broken up, causing unsteady running. In the notes on lubrication the best forms of oil grooves will be discussed. The back layshaft bearing is of very simple form, and may, or may not, be fitted with oiling ring. This bearing is shown in Fig. 26, and the governor driving wheel is here shown keyed on to the end of the layshaft. Oil box lids are fitted to each bearing; the attendant must be careful to keep these closed. The oil from such bearings is used over and over again, but it must be filtered periodically.

Large gas and heavy oil engines are fitted with a crosshead similar to that in a steam engine. Fig. 27 shows one form of crosshead, the body of which is made of cast steel. The gudgeon pin is a tapered fit, and is held in position by two nuts. The piston rod is fixed by means of a cotter. Cast-iron slipper pieces or shoes are fitted to the crosshead and held in position by set pins. A crosshead such as this with only the bottom circular surface is used in the Illmer gas engine. Fig. 28 is a drawing of piston and crosshead combined. The guides are of cylindrical form.

The attendant will do well to make himself familiar with the various parts of the gas or oil engine, and with their names. Figs. 29 and 30 represent the chief parts, and the table on p. 35 will be found useful.

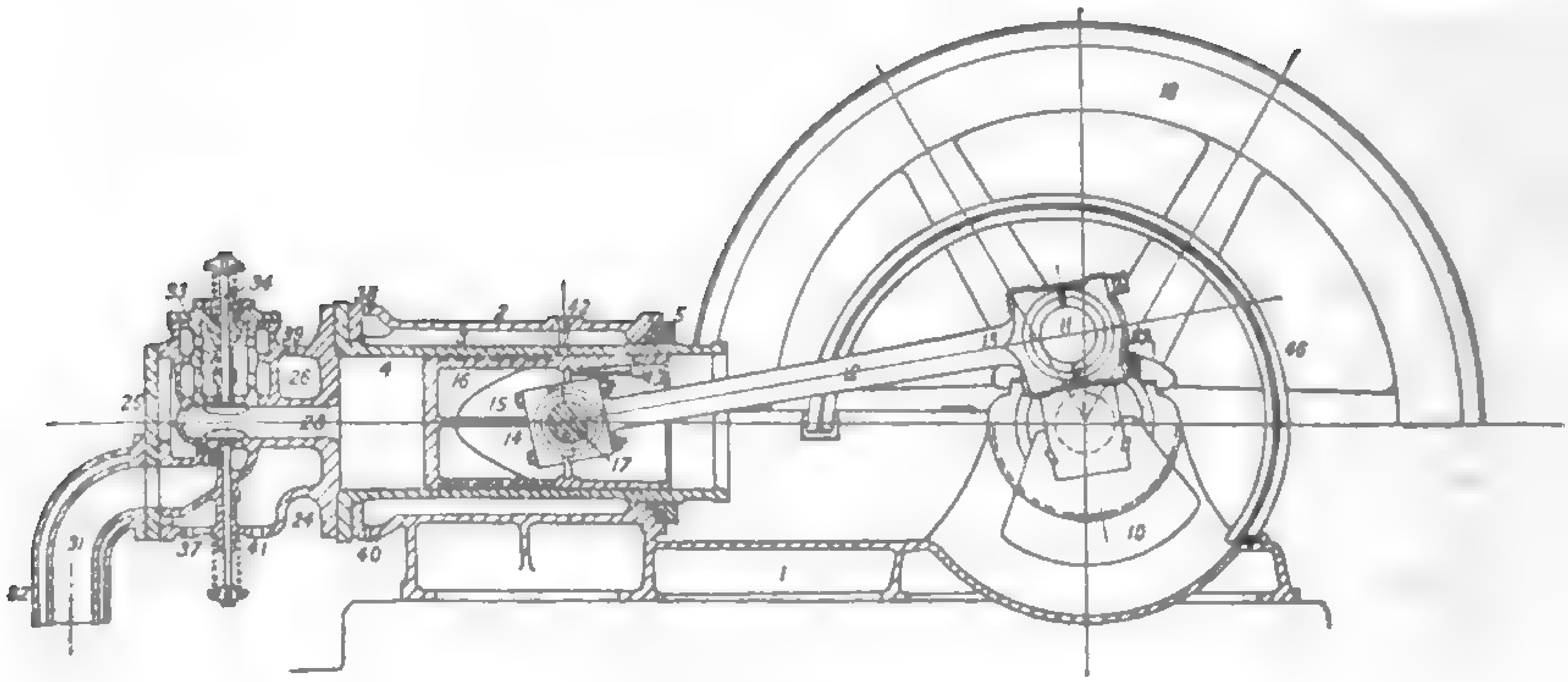


Fig. 29.

Gas Engine (Name of Parts)—Elevation.

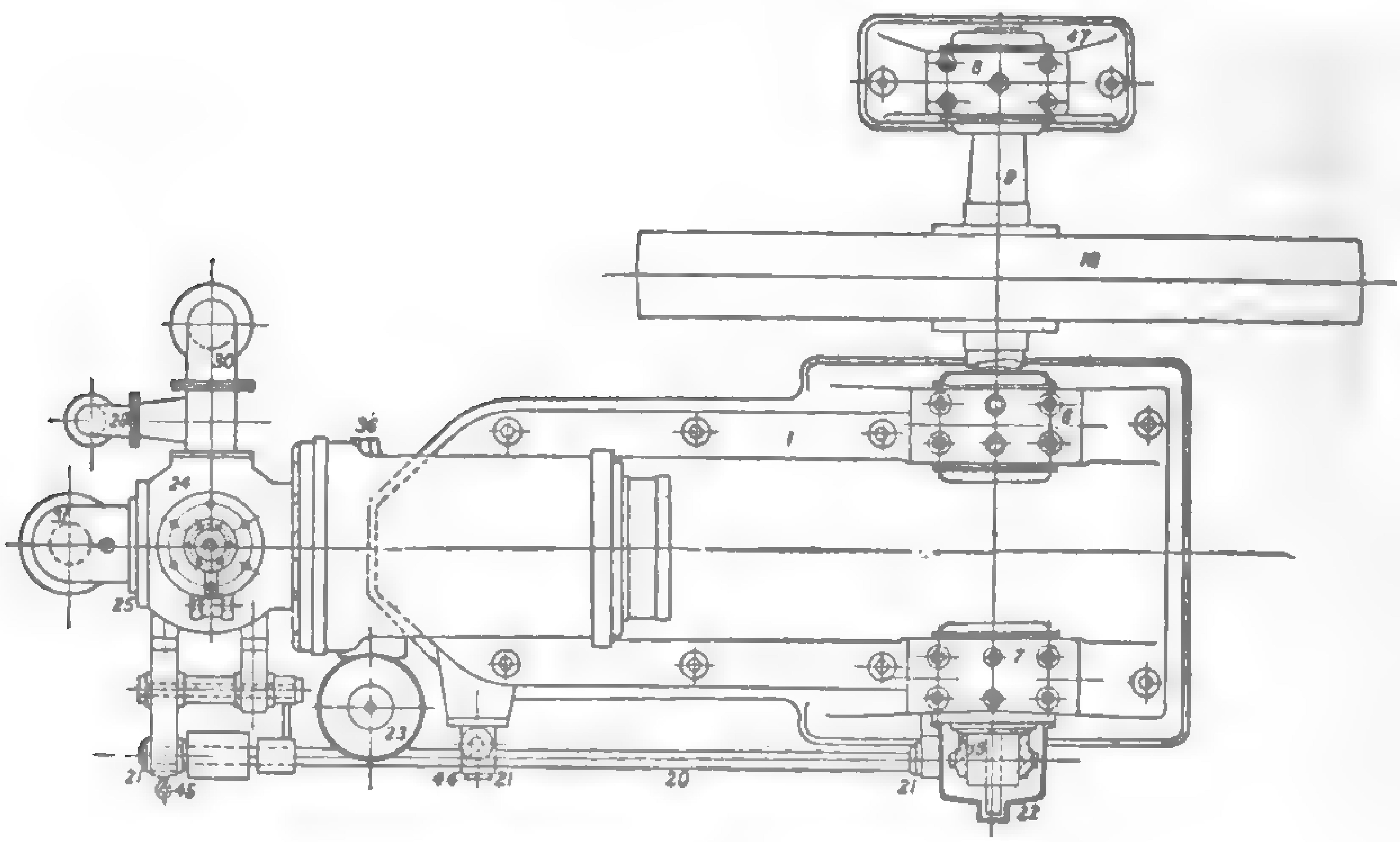


Fig. 30.

Gas Engine (Name of Parts)—Plan.

No.	Part.
	Frame.
1	Frame or bed.
2	Cylinder water jacket.
3	Water space.
4	Cylinder liner.
5	Liner joint ring (to water jacket).
	Bearings.
6	Main bearing, flywheel side.
7	Main bearing, side shaft (outer) side.
8	Out-end bearing.
	Shaft.
9	Crankshaft.
10	Balance weights.
11	Crankpin.
	Connecting Rod.
12	Connecting rod.
13	Big end (crank end) of connecting rod.
14	Small end (piston end) of connecting rod.
	Piston.
15	Piston.
16	Piston ring.
17	Piston pin (crosshead).
	Flywheel.
18	Flywheel.
	Gearing.
19	Crank worm (driving valve gear).
20	Sideshaft.
21	Sideshaft bearing.
22	Guard for gearing.
	Governor.
23	Governor.
	Valve Gear.
24	Breech end.
25	Breech end cover.
26	Water jacket to valves.
27	Mixing chamber for gas and air.
28	Combustion chamber.
29	Gas pipe.
30	Air pipe.
31	Exhaust pipe.
32	Water jacket to exhaust.
	Valves.
33	Admission valve block.
34	Admission valve.
35	Exhaust valve.
	Cooling Water Pipes.
36	Cooling water inlet to cylinder.
37	Cooling water inlet to breech end.
38	Cooling water outlet from cylinder.
39	Cooling water outlet from breech end.
	Drain Cocks.
40	Facing for drain cock for cylinder jacket water.
41	Facing for drain cock for breech end jacket water.
	Lubrication
42	Facing for piston lubricator.
43	Piston pin lubricator.
44	Oil pump for above.
45	Lubricator for sideshaft bearing.
46	Crank splasher guard.
47	Oilguard on main bearing.

CHAPTER III

OIL ENGINE PARTS

The oil engine chosen here (Fig. 31) is built on the lines of usual gas engine practice, and therefore all the main parts will have the same names and uses. The attendant will have little difficulty in making a comparison, the only real difference being the addition of a sprayer valve and the extension of the breech end to form a vaporiser. After vaporisation of the oil by heating it the engine becomes a gas engine; this vaporisation takes place about 600° F. Such engines, but of the vertical type only, have been used in marine work. In some of those engines, such as the 15-h.p. Campbell engine illustrated in Fig. 32, there is no separate fuel valve, the fuel being admitted through small holes drilled in the seating of the inlet valve. Here again this engine closely resembles the gas and semi-Diesel engines built by the same firm. A larger scale section drawing through the inlet valve is shown (Fig. 33), from which it will be readily understood how the high velocity of the incoming air breaks up the oil to form a fine spray. The oil is then said to be "atomised."

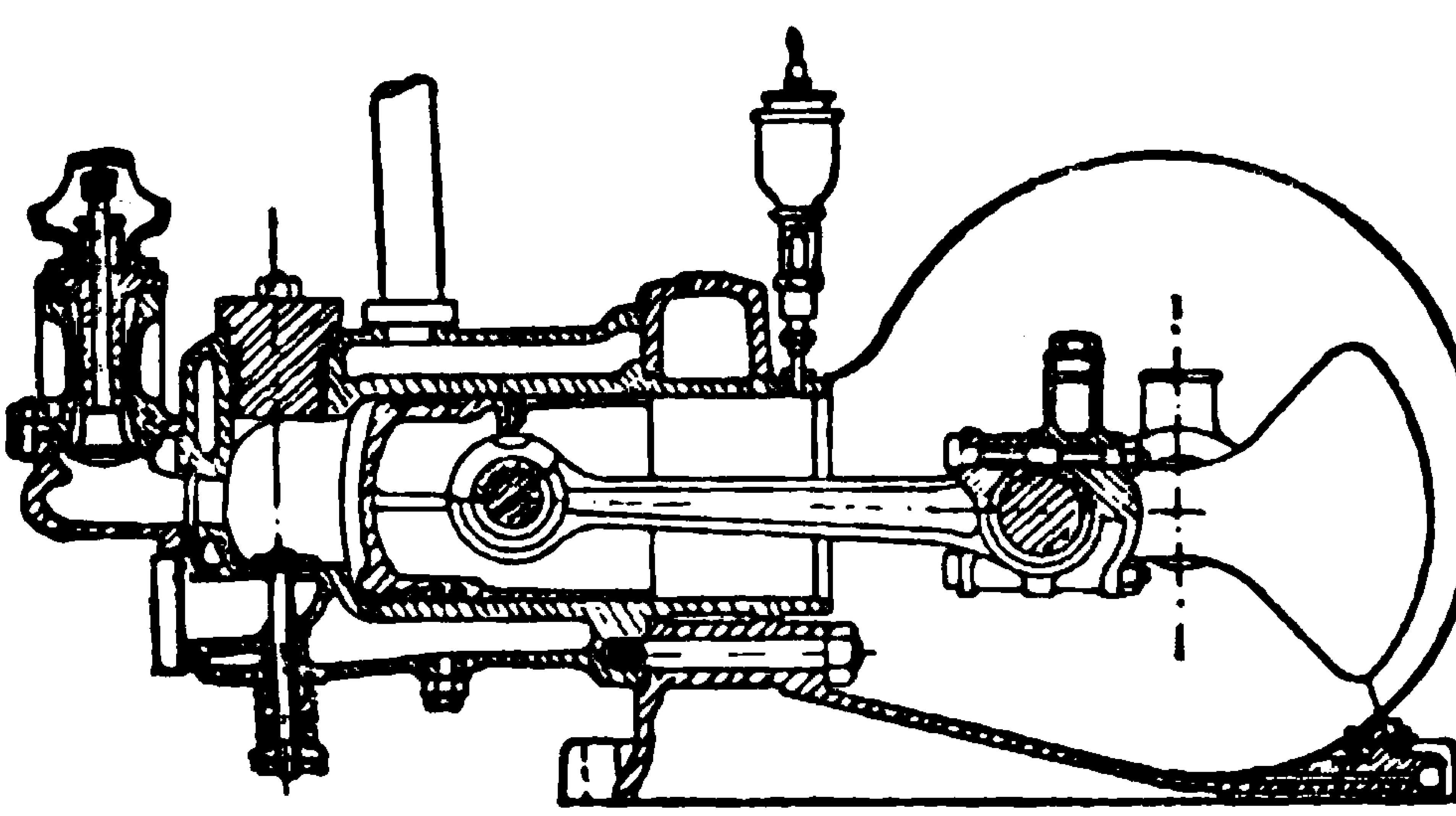


Fig. 31.
Oil Engine.

Campbell Oil Engine (Parts of Inlet Valve)

1. Valve plug.
2. Valve and spindle.
3. Air inlet passage.
4. Oil inlet passage.
5. Oil inlet holes.
6. Inlet valve spring.
7 and 8. Adjusting nuts.
9. Starting screw.

An eccentric is used to open the exhaust valve at the proper time.

This engine can be made reversible. In engines of the class first shown, unless the engine is working at full load and maintained very steady at this load, a separate lamp is kept burning while the engine is working. This lamp, in the case of the National Gas Engine Company's oil engines, may be dispensed with, due to the addition of a timing appliance which causes ignition to take place correctly

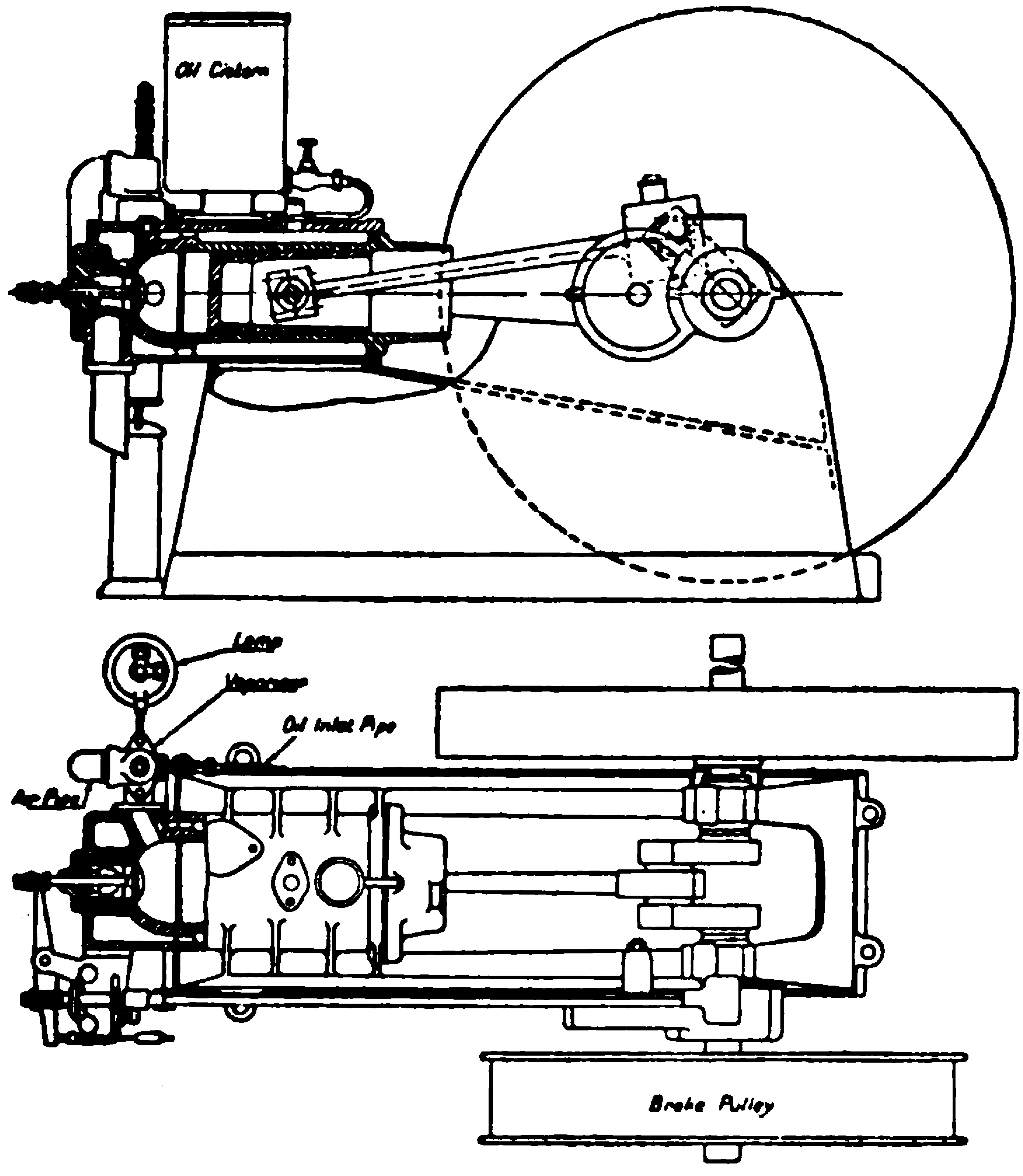


FIG. 32.
CAMPBELL OIL ENGINE.

at all loads. Those attendants who are acquainted with the National gas engine will have no difficulty in working this company's oil engine. The method adopted by the latter makers for vaporising the oil is illustrated in Fig. 34. Another engine, made by Messrs. Tangye, Ltd., can be converted from a gas engine using producer gas to an oil engine inside half an hour.

Vertical gas engines are similar in general, cylinder, and valve gear design to the horizontal engine. Small engines have their cylinders

supported on steel columns screwed to a cast-iron base, while others have a cast-iron crank case which fits between the cylinder and the cast-iron base. It is quite common in vertical cylinders to do without the cylinder liner, as the cylinder in the vertical engine is of a very simple form. Compound engines have been built, but have not proved a great success. The "Rowden" gas engine was of the compound vertical type. Vertical engines are often made with four cylinders. There is very little extra detail in these engines, and this form of construction is very compact when high power is required.

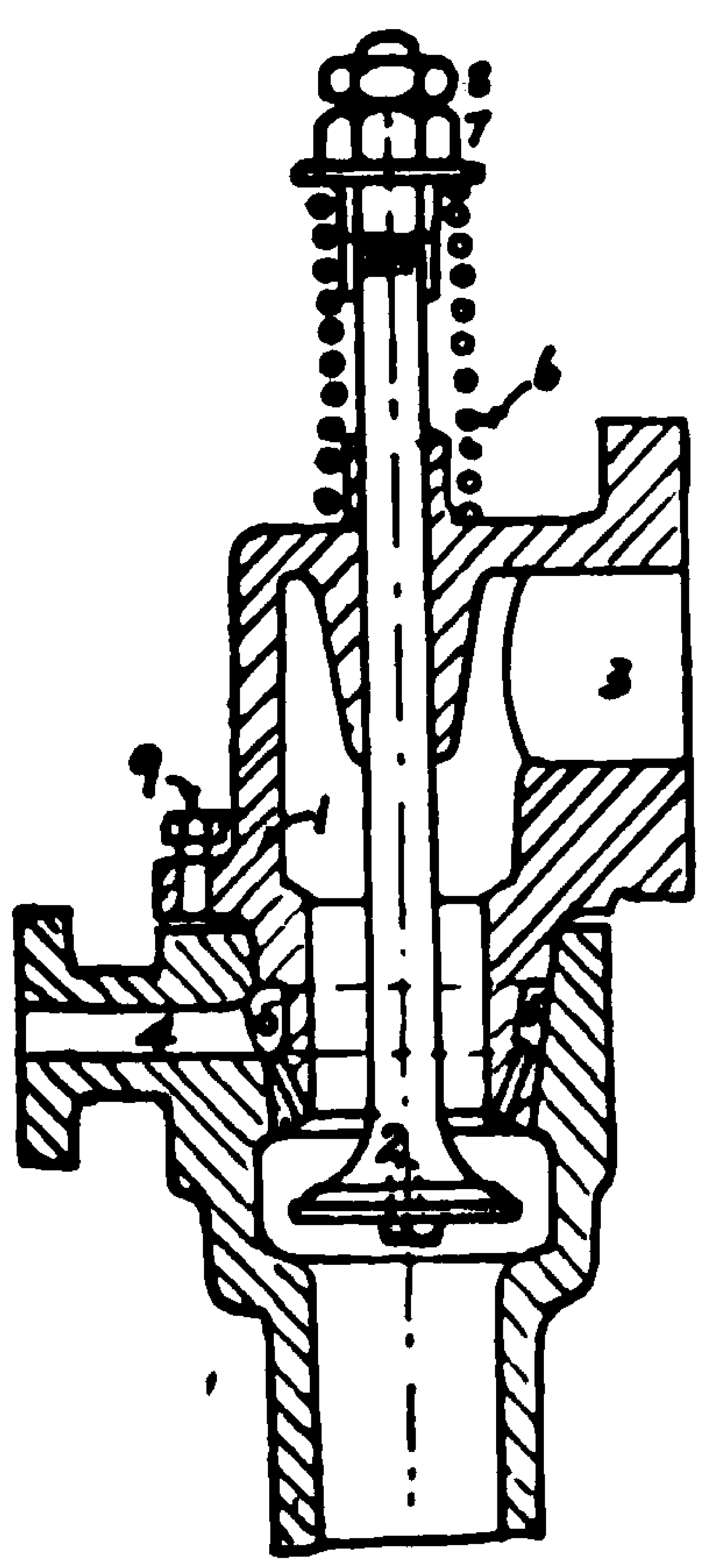


FIG. 33.
ENLARGED SECTION OF CAMPBELL INLET VALVE.

Owing to its extreme simplicity and reliability, surface ignition or hot bulb engines use, almost exclusively, the two-stroke principle, usually with crank case compression. The crank chamber C (Fig. 35) is totally enclosed, and on the instroke of the piston air is drawn into it through the light flap valves *A*. The piston's outstroke compresses this air to 6 or 8 lb. per square inch, so that when port *G* is uncovered the charge of pure air rushes through *D* into the cylinder, and is deflected upwards by the shaped piston head so as to scavenge effectively the bulb *H* of burnt gases which escape by the exhaust ports *E*. The rising piston traps this charge of air and compresses it to 120 or 150 lb. per square inch. At the correct moment, slightly before the dead centre, a charge of oil is injected by the fuel pump through the nozzle *J* into the hot bulb *H*, where it ignites on contact with the hot surface. The maximum pressure attained by combustion ranges from 250 to 300 lb. per square inch, and is reduced to 15 or 20 lb. per square inch during expansion before the exhaust port is uncovered by the piston. The top edge of the exhaust port is slightly higher than the inlet, so that most of the exhaust gases have time to escape before the air can enter to blow the remainder out. The entire absence of complicated valve gear and springs, with their constant need of attention and risk of breakdown, is conspicuous, and a power stroke is obtained every revolution. Pre-ignition cannot take place, since air alone is compressed. The fuel pump and its valves constitute the only delicate part, and it is entirely removed from all temperature stress and is under easy observation. The engine sketched in Fig. 35 is of the "Bolinder" or "G.S.T. In-

vincible " type, and is broadly typical of the largest class of surface-ignition, two-stroke engines with crank case compression. For starting up, an ordinary type of paraffin blow lamp is used to heat the bulb *H* inside the case ; under load the bulb remains hot enough by the heat of combustion.

Some older designs are inclined to give trouble at light or no load through the bulb becoming too cool for ignition and requiring the external heat from the lamp to keep the engine in working condition. In order to remedy this the other extreme is sometimes touched, and trouble may be expected from the bulbs overheating

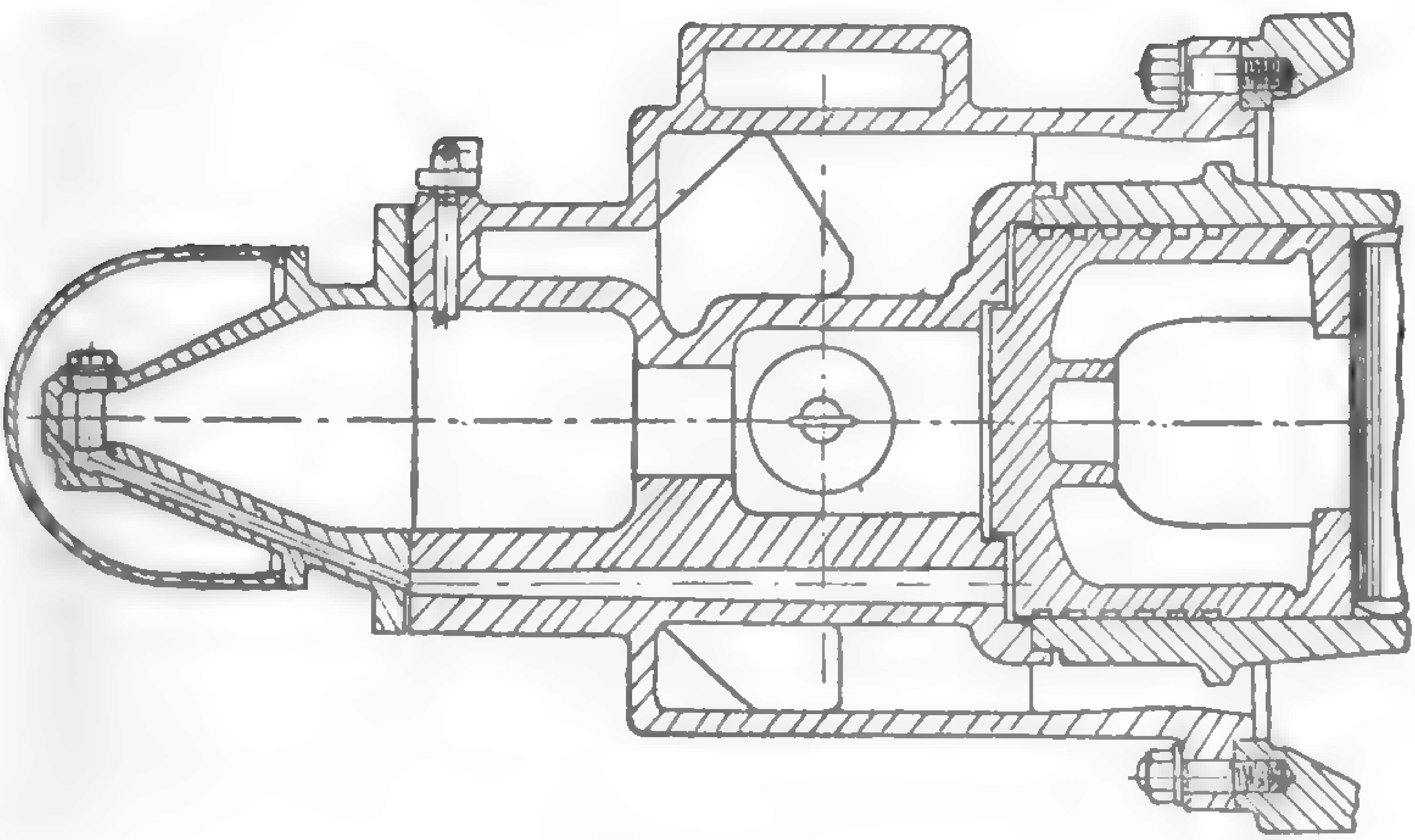


FIG. 34.

SKETCH OF NATIONAL VAPORISER AND METHOD OF IGNITION.

and softening under heavy load. To overcome this, water may be introduced to keep the bulb cool at heavy loads. This can be done by blowing in a water drip along with the scavenging, air thus cooling the bulb. Alternatively, the correct amount of water may be forced in along with the oil spray by means of a separate and similar pump. All this means added complication, and the fact that engines can be designed which will run perfectly at no-load, on loose pulley, without the lamp, and yet do not overheat at full or overload, shows that such expedients as water injection are to be regarded as unnecessary and therefore objectionable. In some engines the desired result is attained by throttling the scavenging air in the transfer passage *D* so that the cooling effect on the bulb is diminished. Other designs

allow for altering the direction of the fuel jet at heavy loads to prevent the normal ignition surface from becoming overheated, and to cause the oil jet to impinge on the hottest parts at light loads. The water spray helps to change the oil into a gas, and both combine by

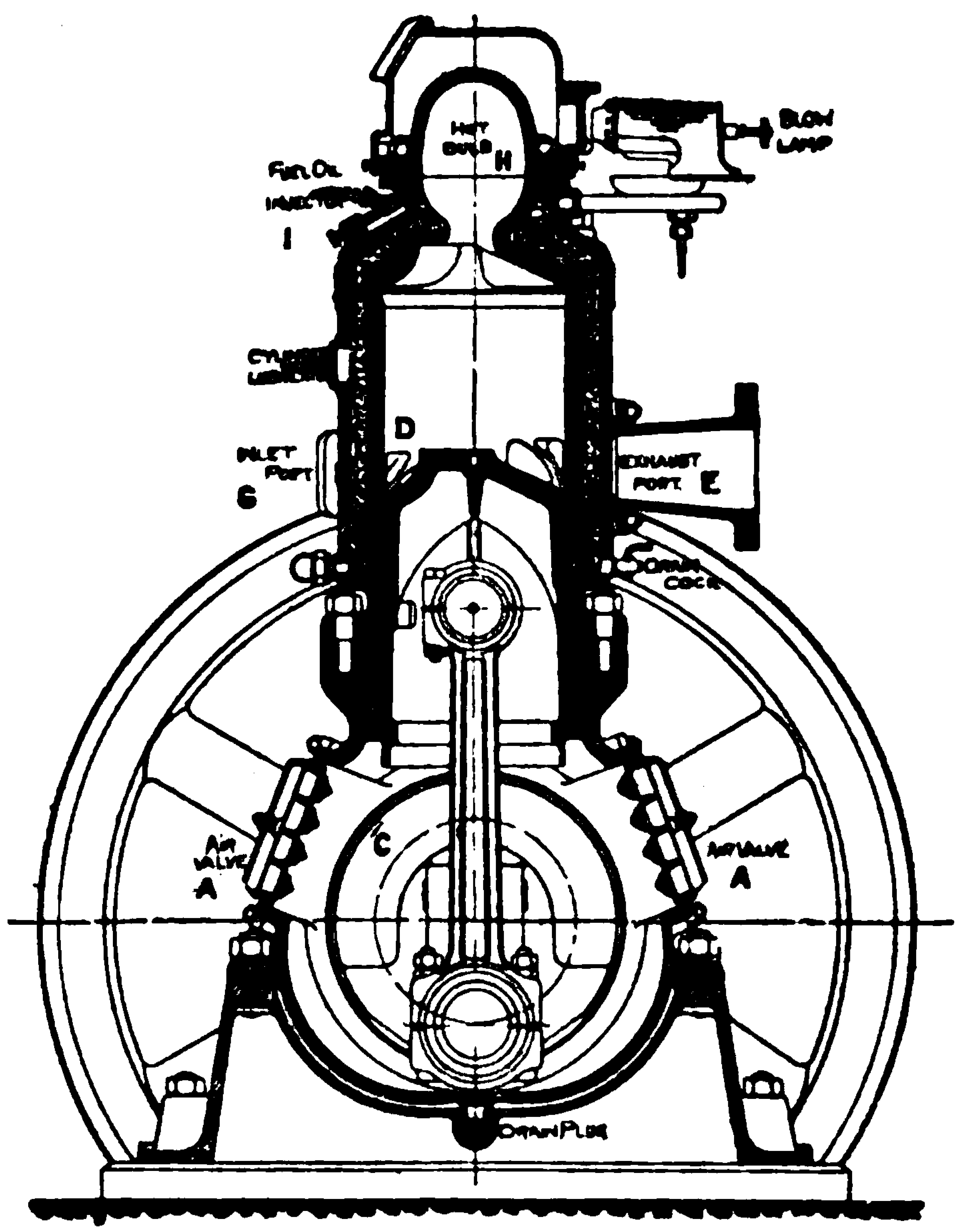


FIG. 35.
CRANK CASE ENGINE.

chemical change to form water gas or producer gas. This chemical change will best be understood when reading the chapter on Producers. Soft water must be used, and an attendant must be careful that the exhaust ports and pipes do not get clogged up by deposits from hard water. Rain water or distilled water is best for cylinder injection.

CHAPTER IV

THE IGNITER

SINCE the gas and sufficient air to form an explosive mixture do not flow in steady streams into the cylinder, but are drawn into the cylinder by the suction of the piston, the supply pipe must be large in order to deliver enough gas for each charge. A reservoir in the form of a rubber gas bag is connected between the gas supply pipe and the gas inlet valve of the engine. This bag receives a constant supply of gas from the meter.

After the engine has compressed the mixture in the cylinder combustion chamber it must be ignited, and this is done in one of the following ways—(1) the hot tube igniter, and (2) the electric ignition system. We may also add (3) the hot chamber for oil engines.

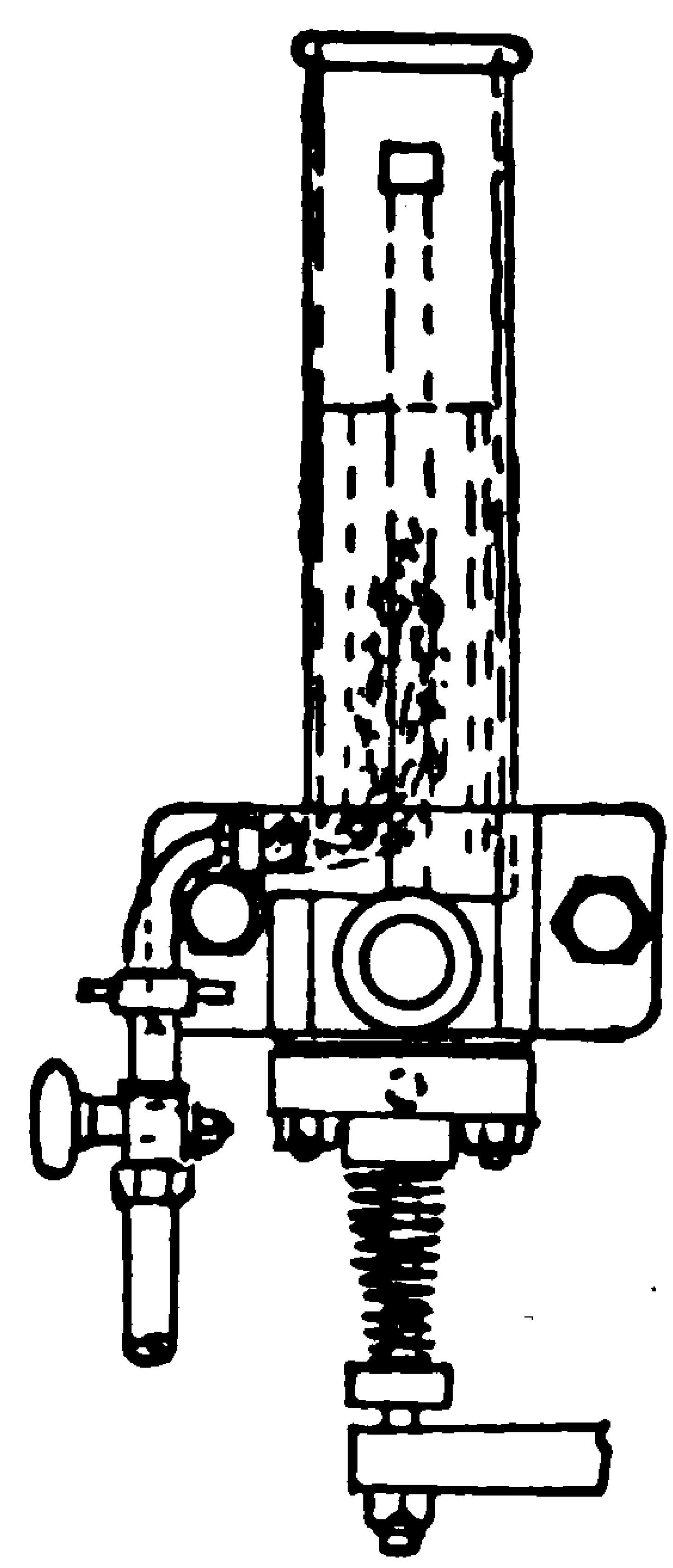


FIG. 36.
HOT TUBE IGNITION.

Quite a number of the smaller or older gas engines make use of hot tube ignition. A small nickel steel or porcelain tube, closed at one end and in direct communication with the cylinder combustion space at the other, is kept red hot by a Bunsen burner. During compression the gas-air mixture is forced up this tube far enough to ignite from the red-hot surface. Besides the direct waste of gas entailed in heating the tube the ignition point is erratic, and admits of only a rough control by varying the length of the tube or the point at which it is heated, so that the mixture may ignite earlier or later, according to the distance it must travel along the tube to meet the hot surface. The burner and enclosing chimney are customarily adjustable for this purpose. This is shown in Fig. 36. It will be quite readily seen that whenever the fuel mixture is compressed either an ignition valve is opened by means of a cam on the cam-shaft, or the piston might be made to uncover a port or hole which opens into the tube. The fuel charge then rushes into the incandescent tube, where it is ignited, and the flame

sweeps back into the cylinder and fires the charge. The dangers attending this system will be considered later. The timing or ignition valves are subject to great heat and, consequently, inadequate lubrication. Large gas engines invariably employ electric ignition, and almost all engine makers are supplying even the smallest engine with an electric circuit.

Electric Ignition

The spark is caused by making a break or gap in the conducting part of an electric circuit. This break is placed in the midst of the

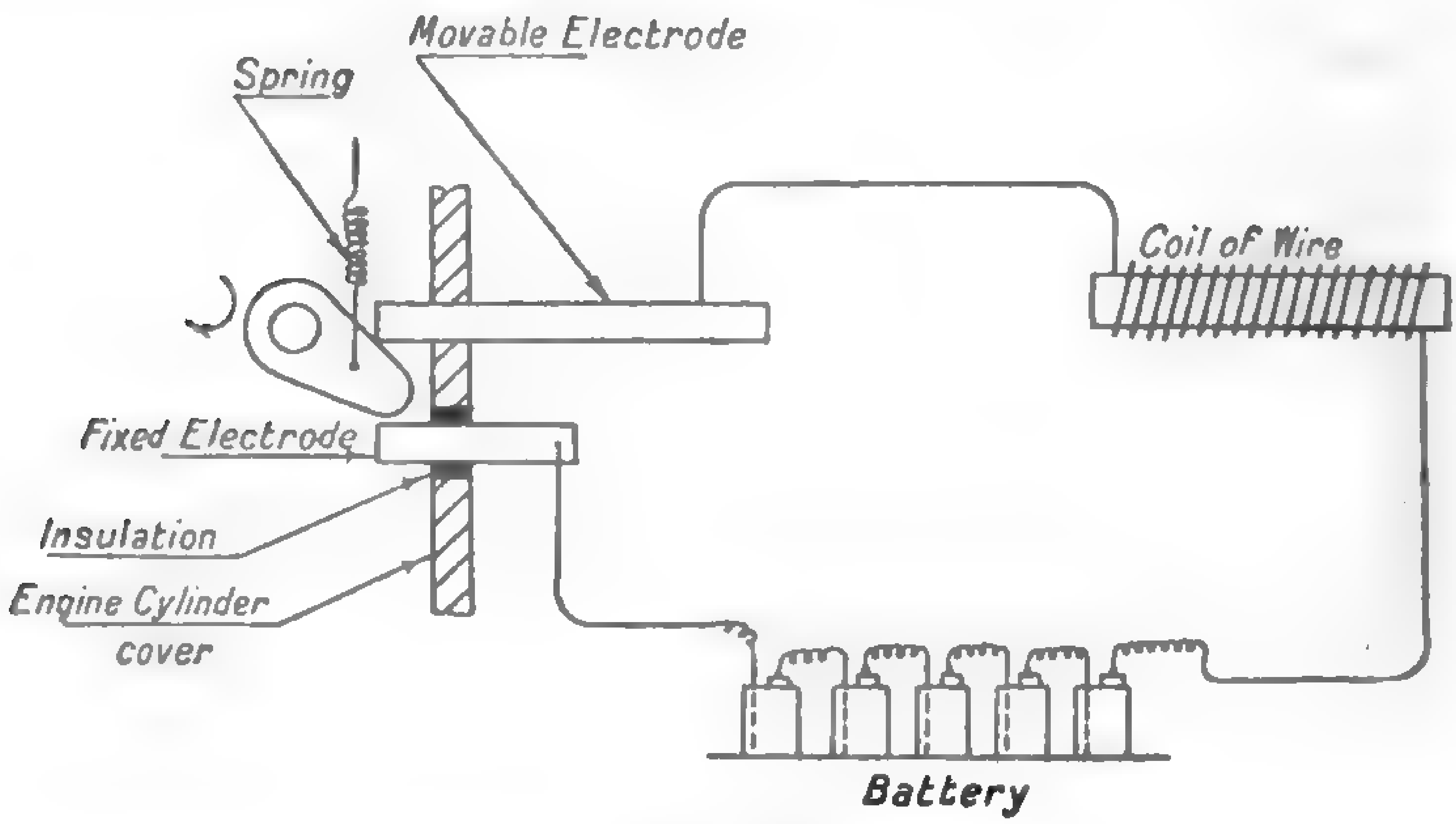


Fig. 37.
Battery Ignition.

combustible mixture, to which the spark communicates its heat. There are two kinds of spark igniters—(1) the battery and spark coil systems; (2) the magneto systems.

If we connect four or five dry cells in series and complete the electric circuit as shown in Fig. 37, and the circuit is then broken by separating the ends of two wires or cutting a conductor, a small spark will be observed at the point of separation. This small spark is useless for ignition, but on placing in the circuit a coil of many turns of insulated wire (say eighteen to twenty standard wire gauge, cotton-covered wire) wound on a soft iron core, as in the sketch, and suitably proportioning the iron core and its coil of wire, we may obtain a good hot ("fat") spark or arc on breaking contact. The electric current flowing from the battery round the iron core quickly

establishes a strong magnetic field, which is quite a big store of energy. When the circuit breaks, this magnetic field releases its energy by trying to make the current keep on flowing, in spite of the gap in the circuit, so that an arc is drawn out by the current bridging the gap. The electricity flowing in the coil has a large inertia, and strongly objects to being suddenly stopped, just in the same way as swiftly flowing water in a pipe may burst the pipe if a valve is suddenly closed at the outlet; the large inertia of the mass of quickly moving water produces a surge of dangerously high pressure. This is just what happens when the electric current is broken—the surge of high pressure (or voltage) keeps the current flowing

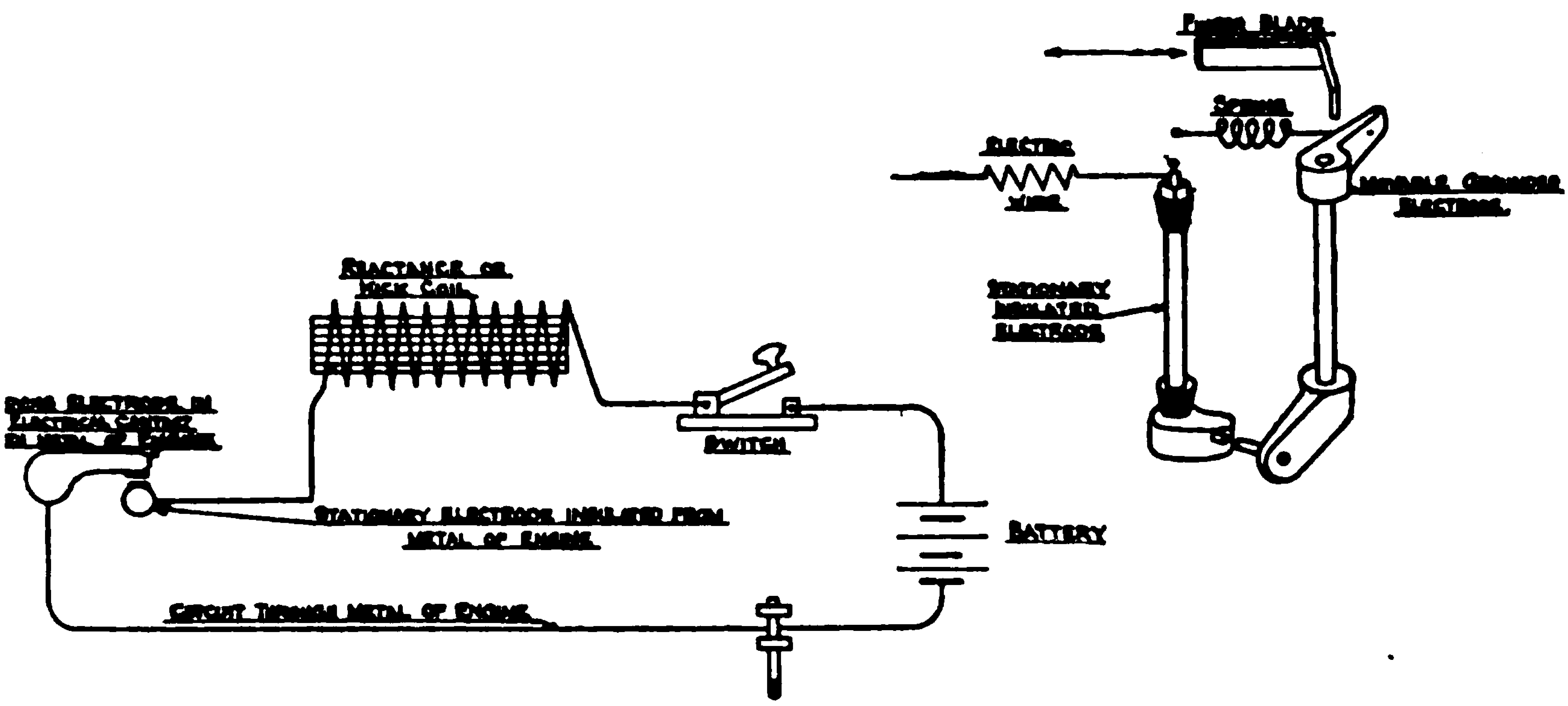


FIG. 38.

SPARK IGNITION AND IGNITER MECHANISM.

across the gap for an instant. In Fig. 38 the ends of the wire are connected to the electrodes, which are well insulated from each other. The igniter mechanism is simply a lever worked one way by the camshaft and returned to position by a spring. This lever connects the two electrodes, and at the right moment the spring makes it snap back, causing a break in the circuit and, therefore, a spark in the combustion chamber.

Fig. 39 shows the usual type of sparking plug for gas engines. Current enters by the terminal *A* along the insulated rod *B*, and then (inside the cylinder) across the lever *C* to the frame of the engine. At the correct instant for firing, the lever *C* is suddenly raised off the terminal *D* by a tappet striking the crank *E* and the spark is created inside the cylinder. The whole plug is a gas-tight fit in the cylinder by the cone face *F*, and the moving rod *H* also has a cone face at *G*.

On some engines the rod *B* is turned slightly round by a ratchet after each explosion, to keep the terminal *D* clear of carbon deposit, and to prevent pitting by the heat of the spark always occurring at one point. The current is supplied by a small battery or by a small dynamo, and the points must be brought together about ·04 of a second before the spark is required. If less time than this is allowed, the spark will be poor, as the flow of current will not be properly established; if contact is longer, current will be wasted. Instead of using a battery it is more usual to employ a low-tension (L.T.) magneto, the simple shuttle armature of which is suddenly jerked through part of a revolution just before the plug circuit breaks. The pressure so generated is only a few volts, but the winding of the armature acts at the same time as the spark intensifying coil. The

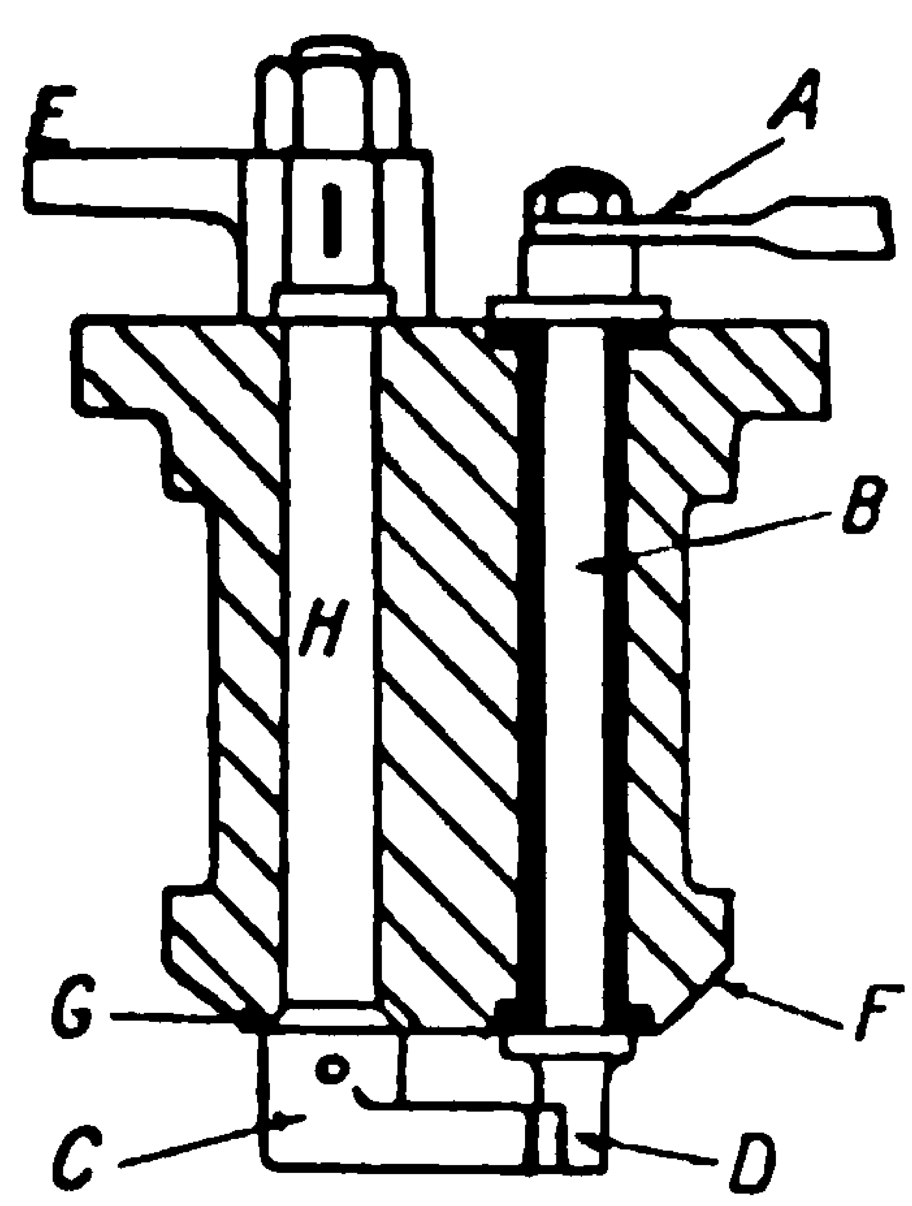


FIG. 39.
SPARKING PLUG.

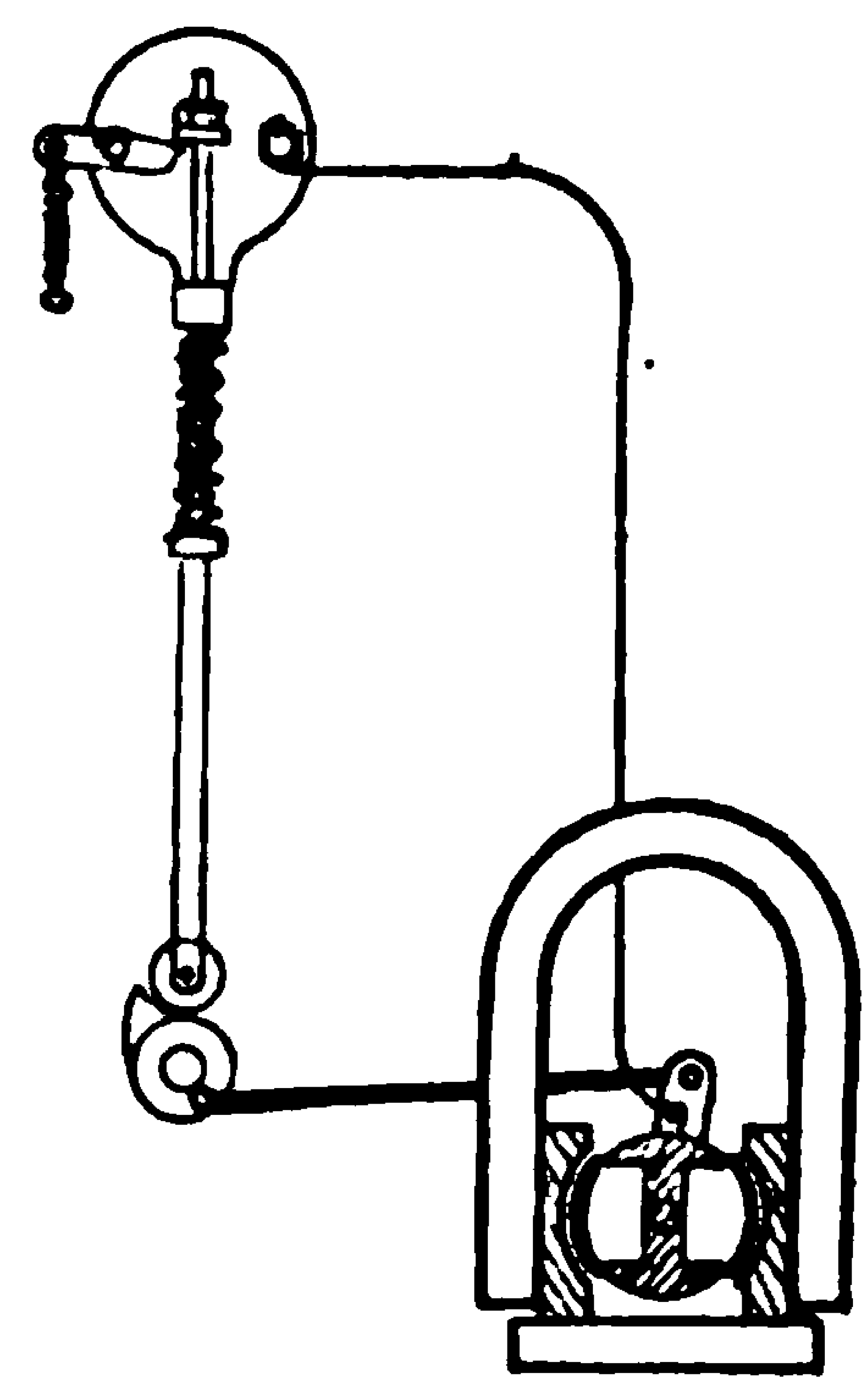


FIG. 40.
IGNITION BY MAGNETO.

magneto and the plug are usually interconnected, and operate from the same cam. One method is shown in Fig. 40, and all systems have the same fundamental idea. The main disadvantage of low-tension ignition is the necessity for having moving parts in the cylinder, where they may become fouled and wear away, but the replacement and cleaning is simple. The control of the firing point is excellent and exact. The contact points *C* and *D* are made of various materials; platinum and platinum-iridium are the most common. Platinum-iridium wears much better than pure platinum. It is in the form of a bead brazed on to the end of the electrode. The bead points vary from $\frac{1}{8}$ to $\frac{3}{16}$ in. in diameter. Platinum, used in wire form, $\frac{1}{8}$ in. in diameter, is brazed or riveted on. When

copper points are used the points taper from $\frac{1}{4}$ in. diameter to $\frac{1}{8}$ in. diameter.

The parts of a low-tension magneto are—(1) the permanent field magnet; (2) the armature core; (3) the coil of wire wound on the armature. The usual form of field magnet is the horse-shoe permanent steel magnet. The armature core is a cast-iron cylinder with grooves cut lengthwise in the opposite sides of it, and having a spindle passing through its centre. A single coil of fine insulated wire is wound in the grooves of the armature, and the ends are connected to brass collector rings, called slip-rings. In some magnetos

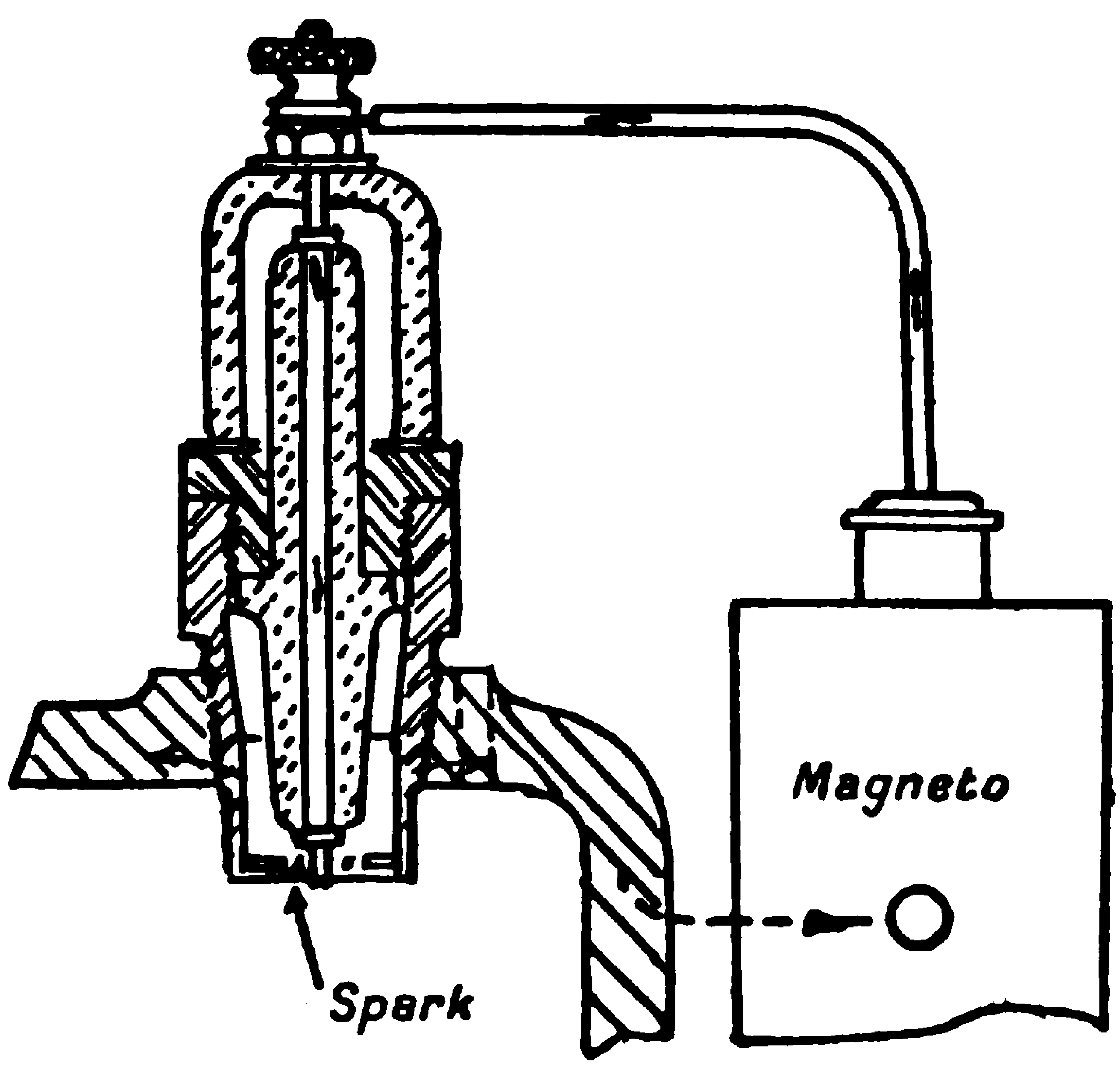


FIG. 41.
HIGH-TENSION SPARKING PLUG.

the armature rotates, but the more common is the oscillating type. The rocking motion is imparted by a push from a spindle or lever, and the return motion is given by strong springs. It is much easier to start up the engine with an oscillating armature than with a full rotation armature.

When sparking plugs are used, as in large engines using a jump-spark igniter, the attendant will not be called upon to have an extra good knowledge of their manufacture. The plugs and timing devices are very specialised accessories, and are bought ready for use. Plugs are usually placed in the cap over the inlet valve. The flanges and facings for these have been shown in previous figures. The points project into the cylinder about $\frac{1}{8}$ in. In the two-cycle

engine the sparking plug is placed in the centre of the cylinder head and on the side nearest the deflecting plate, and away from the exhaust pipe. Two sparking plugs are fitted in large cylinders, and in many cases a faulty plug may be removed while the engine is running. The sparking plug is therefore a device which introduces a high-tension current into the combustion chamber, insulates the conductor from the walls, and also forms an insulated support for

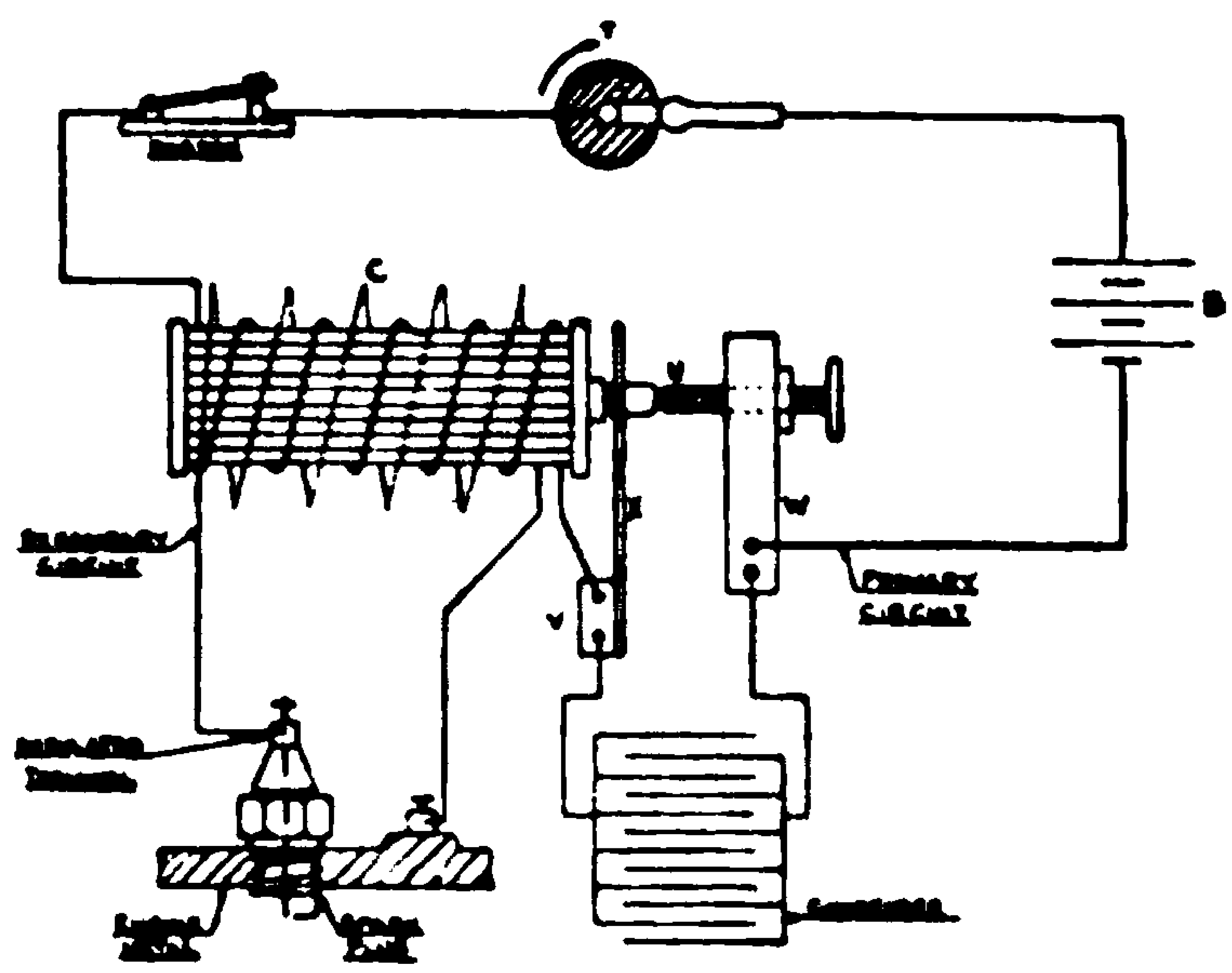


FIG. 42.
ELECTRICAL H.T. CONNECTIONS.

the spark gap electrodes inside the cylinder. Fig. 41 shows a diagrammatic sketch of a sparking plug. The attendant must be careful when screwing a plug into the cylinder. The porcelain is readily broken; this breakage often takes place after the engine has heated up. It is therefore advisable to screw the plug into the cylinder just sufficiently tightly to keep gas from escaping, and then tighten lightly when the engine is hot.

Fig. 42 shows the usual electrical circuit and connections when high-tension (H.T.) ignition is used.

CHAPTER V

GOVERNING

THE power developed by the engine depends upon the amount of gas with which it is supplied, so that governing the speed of the engine is a matter of arranging for the correct quantity of gas. The three main methods of accomplishing this are "hit-and-miss," "quantity" and "quality" governing; sometimes the two latter methods are combined.

"*Hit-and-miss*" governing, as the name implies, is effected by missing out entire explosions, by the simple expedient of leaving the gas valve closed during the suction stroke, so that air only is drawn in. The air scavenges and cools the cylinder, so that the first explosion after a series of misses will be a larger one than at heavy loads, since a larger and purer charge can be taken into the cooler cylinder. At very light loads this cooling may cause slow burning (*i.e.*, a poor explosion) of the charge, calling for a slightly richer mixture. This gives a very economical method, particularly at light loads, but cannot be used if exact speed maintenance is important. It is commonest on all small engines, but is not used above 150 h.p. Naturally it is not very successful on light loads with a suction gas plant, since the intermittent draught in the fire produces poor gas. The detail arrangement is shown in Fig. 43, while in Fig. 44 is shown the arrangement in diagrammatic form. Cam C

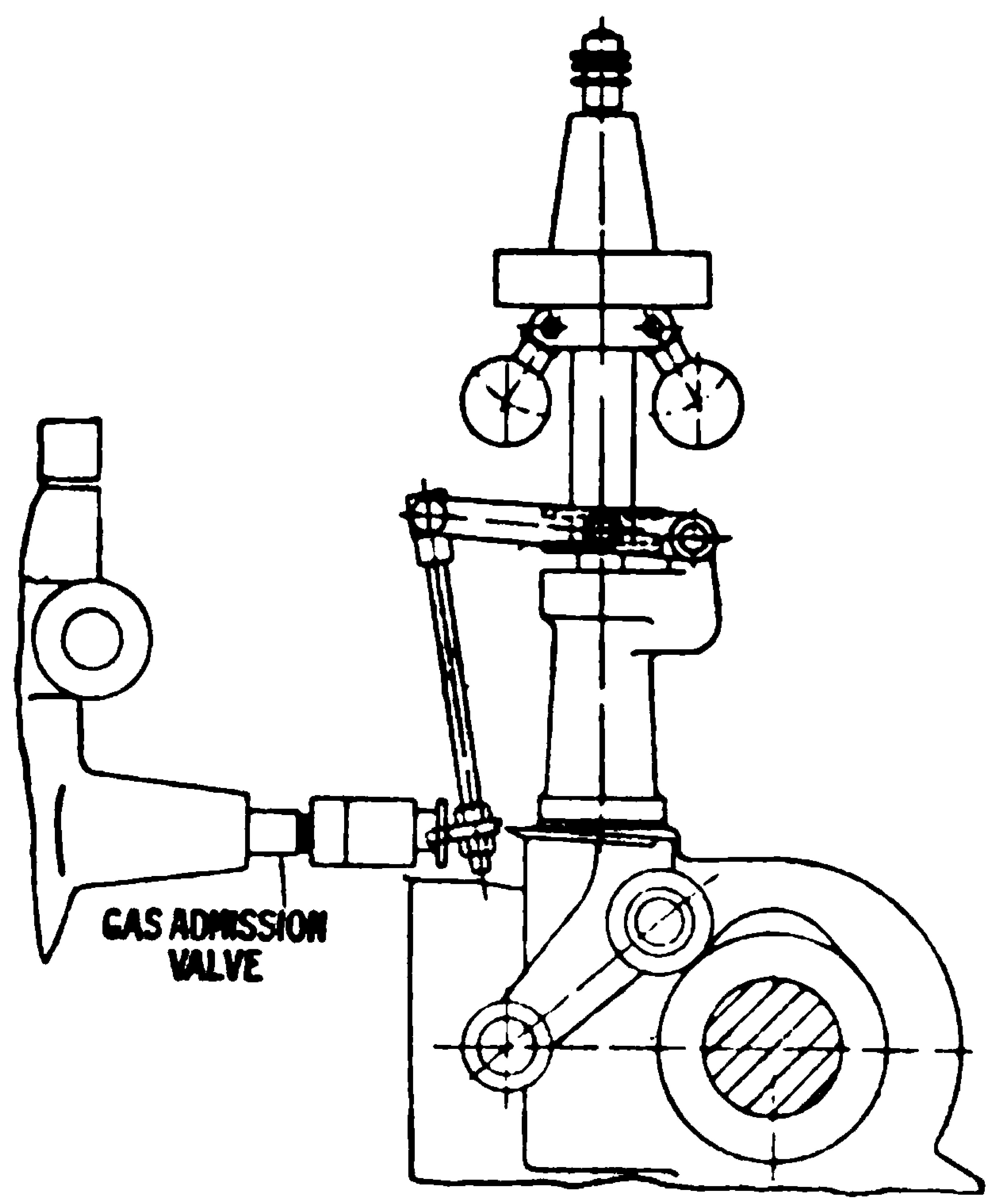


FIG. 43.

DETAIL ARRANGEMENT OF "HIT-AND-MISS" GOVERNING.

pushes the roller *D* and opens the valve *A* by rocking the lever about the fixed point near its centre. *B* is attached to the governor, and may, or may not, be in line with the projection on the lever and stem of valve *A*. When the speed of the engine is too high, the governor lifts *B* out of this line, and consequently, though the lever is rocked by the cam, the valve *A* receives no motion. As the engine slows down, *B* is inserted by the governor, and the next time the lever is rocked by the cam the valve is opened. It will be clearly seen that as the governor balls increase in speed of rotation and raise the governor sleeve with rod attachment the whole of the fuel supply may be cut off for one or more strokes.

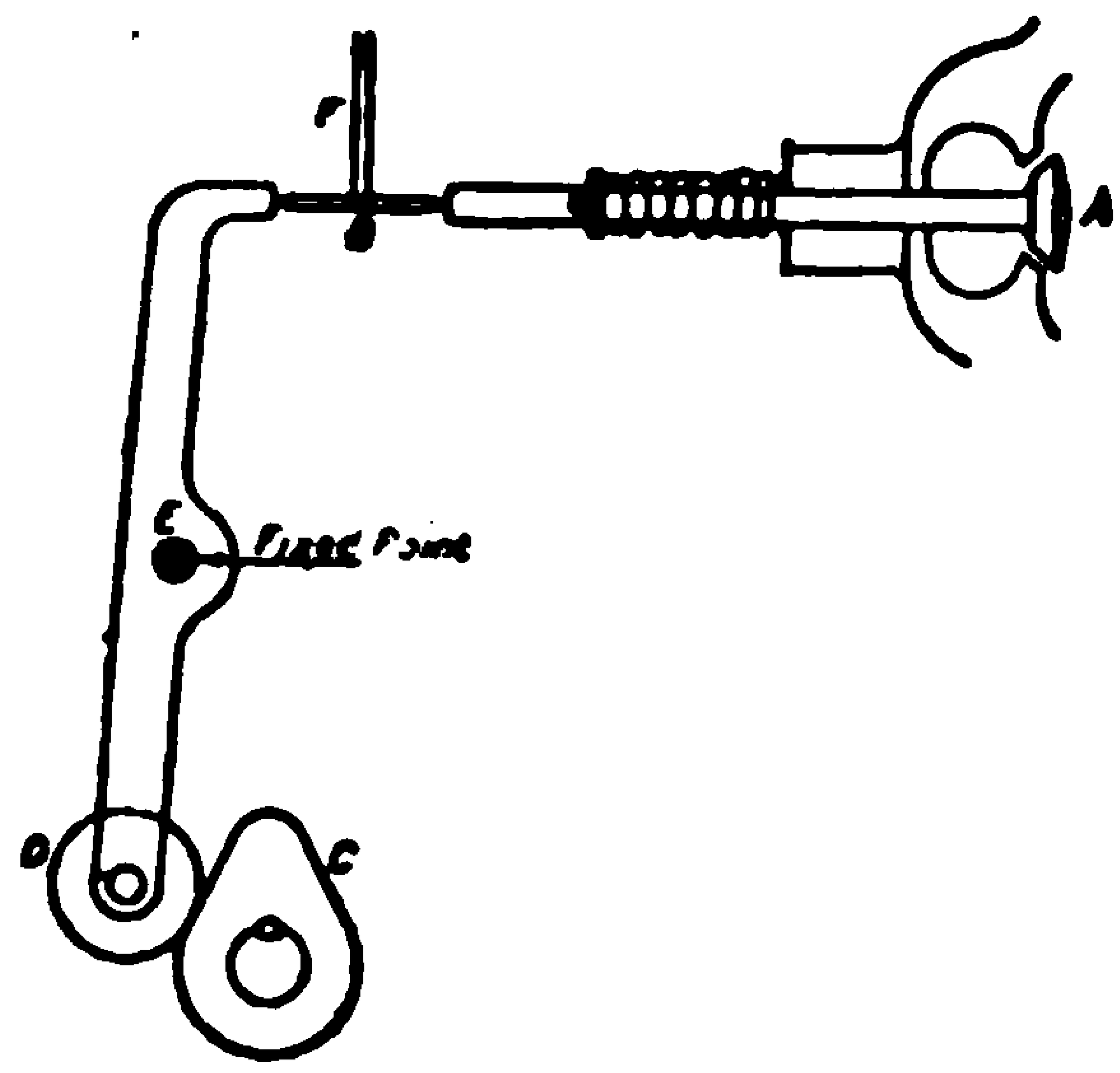


FIG. 44.
DIAGRAMMATIC ARRANGEMENT OF "HIT-AND-MISS" GOVERNING.

"*Quantity*" governing is the most usual on all large gas engines. The proportion of gas to air remains constant, but the amount admitted on the suction stroke is controlled, either by throttling the gas and air or by closing the admission valves before the piston completes the suction stroke. Since the efficiency of the engine depends so largely on high compression, the smaller compression which results from this smaller charge means a loss of efficiency, which, however, is not serious until below half load. The constant quality ensures freedom from ignition troubles, but the lower compression at light loads requires to be met by advancing the spark, since the burning is slower. This throttling of the working charge of air and gas as it is about to

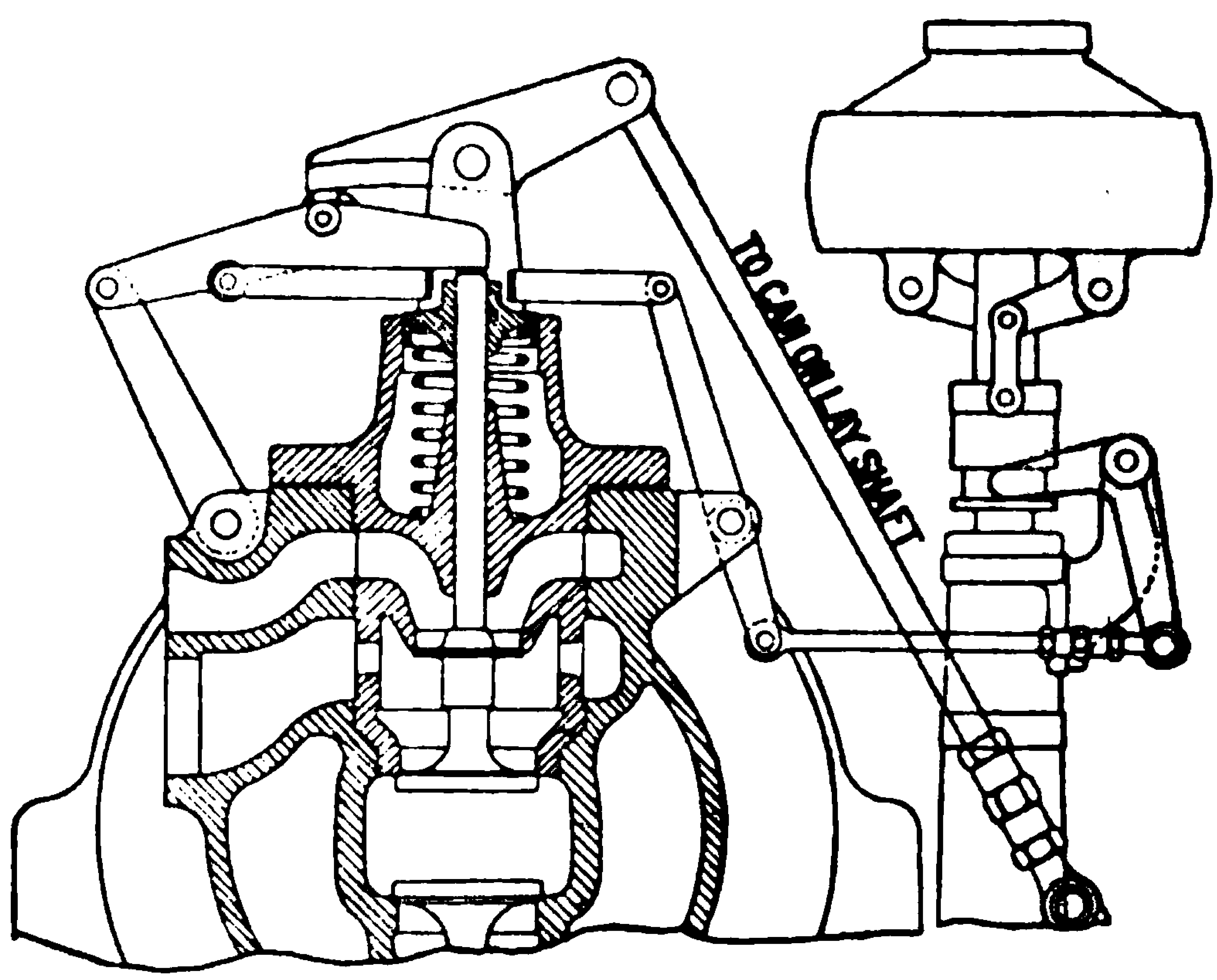


FIG. 45.
QUANTITY GOVERNING (TANGYE ENGINE).

enter the cylinder may be done automatically by the governor. Still, the strength of the mixture may be regulated by the attendant to suit the quality of the gas coming from the producer. Quantity working comes most nearly to that of the steam engine cut-off gear.

In the Tangye engine (Fig. 45) the valve rocker works against a fulcrum, the position of which is varied by the governor. The lift of the combined air and gas valve can be varied although the length of the push rod is kept constant. Other engines made by Messrs. Tangye employ a valve auxiliary to the main air and gas valve, and the governor works this auxiliary valve. The no-load gas consumption is about one-third of that at full load.

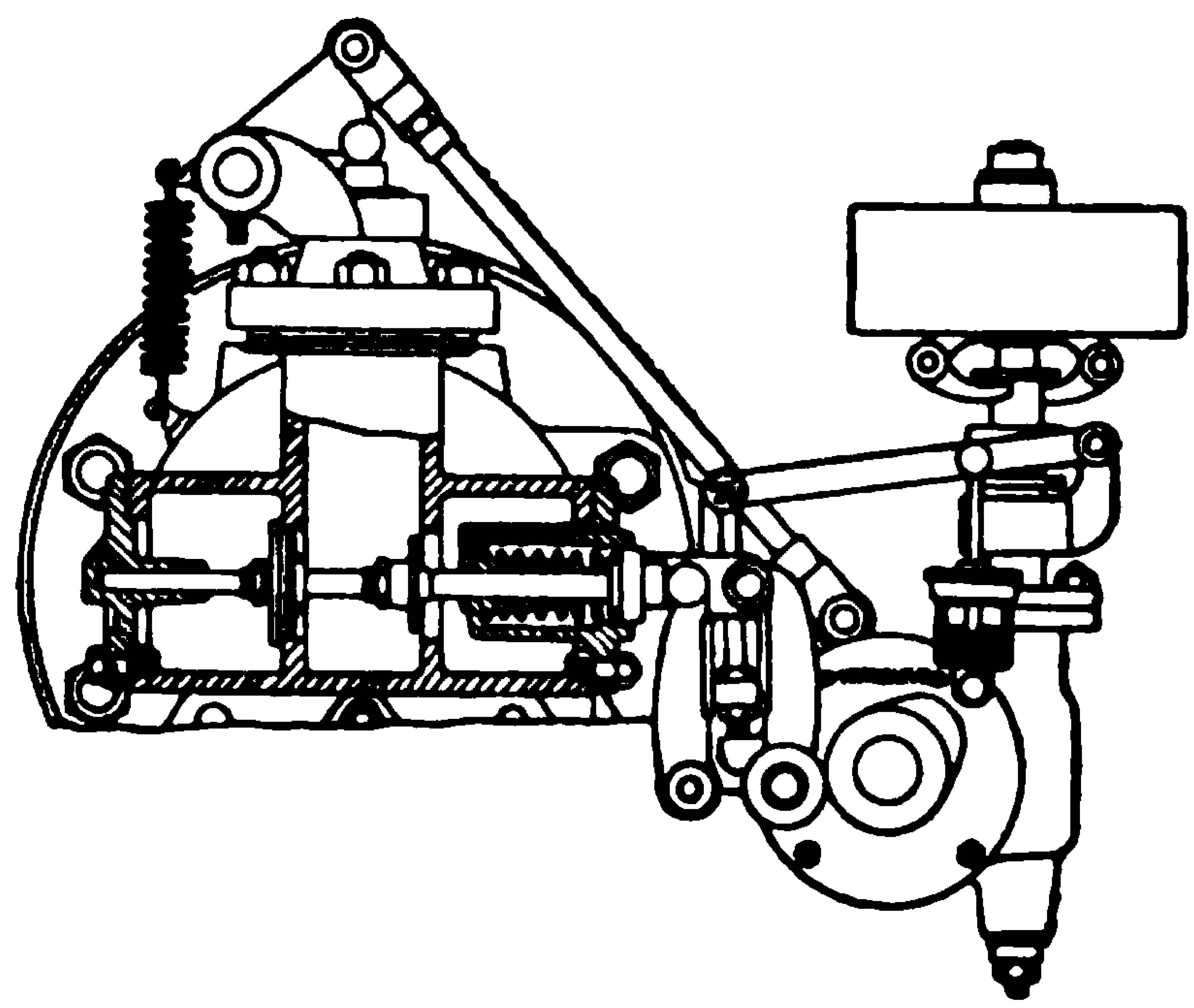


Fig. 46.
Quality Governor.

"*Quality*" governing. The governor is here used to reduce the richness or quality of the working charge. In this system the compression pressure is maintained by admitting a constant amount of mixture, the gas only being throttled down for light loads. This reduces the mean thermal value of the charge admitted, with the result that the pressure produced is less and the engine speed falls to its normal value. The composition of the mixture is continually varying, and it is not possible to find any fixed ignition point to suit all mixtures. Ignition troubles are thus introduced at light loads, but as the compressions are constant, and governing is very exact, the engine runs sweetly unless the mixture is made too weak, when it will not fire. It is clear that at low loads this method of

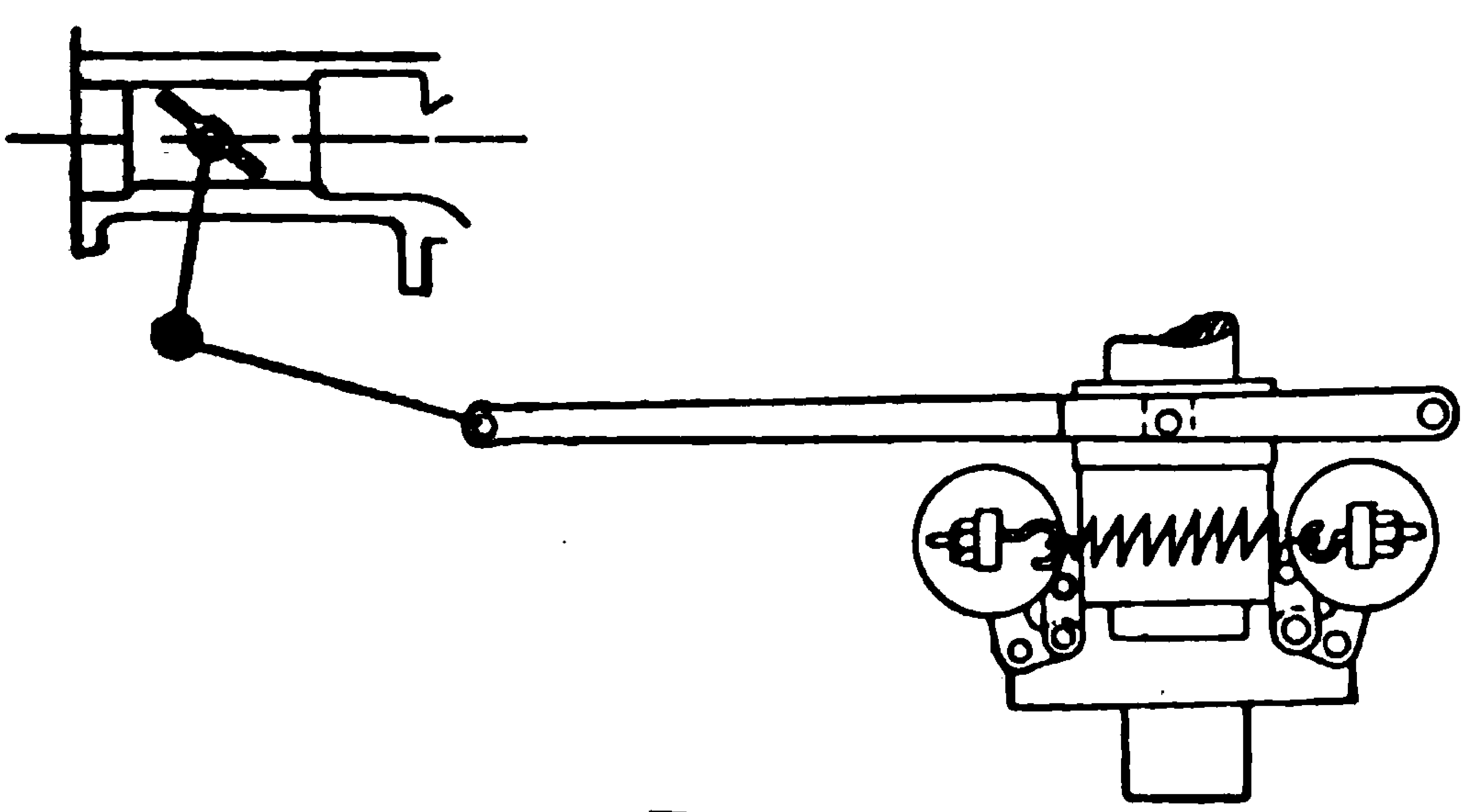


Fig. 47.
Shaft Governor.

governing is extremely inefficient, the weakened mixture giving slow combustion and large heat loss to the jacket water. Where the engine is nearly fully loaded all the time, or where cheap gas, like blast furnace gas, is used, the mechanical advantages make the system very useful. The no-load consumption may amount to half that at full load. Fig. 46 does not require any description, as it is much the same as the previous detail drawings of governing systems.

Some of the advantages of all three systems may be secured by a combination of the various methods. For example, "quantity" and "quality" governing at high loads can be used with "hit-and-miss" governing at low loads. For exact speed regulation, as in dynamo driving, "quality" governing at high loads and "quantity" governing at low loads tends towards economy and avoids speed fluctuation trouble.

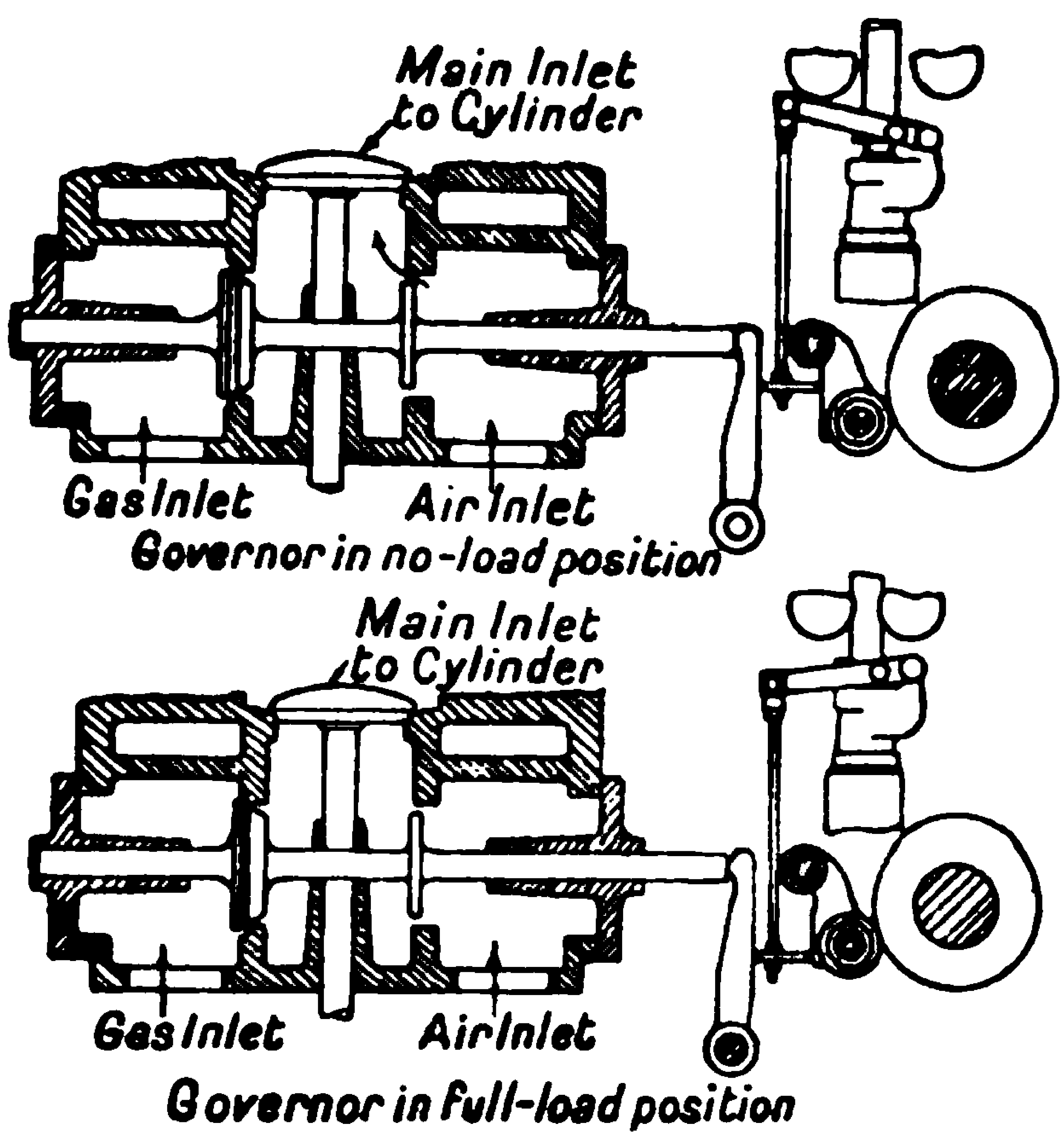


FIG. 48.
NATIONAL ARRANGEMENT.

The governor usually employed needs little description; the centrifugal weights are spring loaded and adjustable for speed while in motion. The construction of the governor may be seen from previous figures, as these are representative types. Centrifugal force of rotating balls moves the sleeve which slides on the governor spindle, and, in moving, raises or lowers a pecher piece, similar to *B* in Fig. 44. The wheels for driving the governor spindle are machined spiral gear, the governor running three or four times as fast as the engine. The attendant must therefore pay careful attention to the oiling arrangements provided on the governor and gear. A crankshaft governor arrangement is also shown in connection with a throttle governor arrangement in Fig. 47. Here the valve rod is moved by the governor, which, in turn, alters the position of a throttling valve, due to the form of a cam-shaped bell-crank lever worked by valve rods.

Another arrangement which is fitted to the National gas engine appears in Fig. 48.

CHAPTER VI

COOLING AND LUBRICATION

Cooling Systems

Very small engines are now being manufactured with fins cast on the cylinder for air cooling, like motor-cycle engines, the draught being produced by a fan instead of motion through the air. The effectiveness of this system depends entirely upon good design, which can make the type extremely serviceable, easily installed, light and portable, and entirely free from winter troubles caused by freezing water. Large sizes of engines are invariably water jacketed, and a free, easy flow of water must be aimed at by avoiding awkward passages in the jacket, particularly where the circulation is on the "thermo-syphon" system. The water, heated by passing through the water jacket of the cylinder, rises, owing to its density being lower than that in the cooler tank, so that continuous circulation is set up as shown in Fig. 49. A little thought will show the advantage of having the tank above the level of the cylinder, since a larger hot column is provided, giving more rapid circulation. The forces moving the water are small, so the importance of large pipes and easy curves is obvious. The tank surface is responsible for most of the final heat dissipation, and must therefore be in a position to receive good ventilation. For this

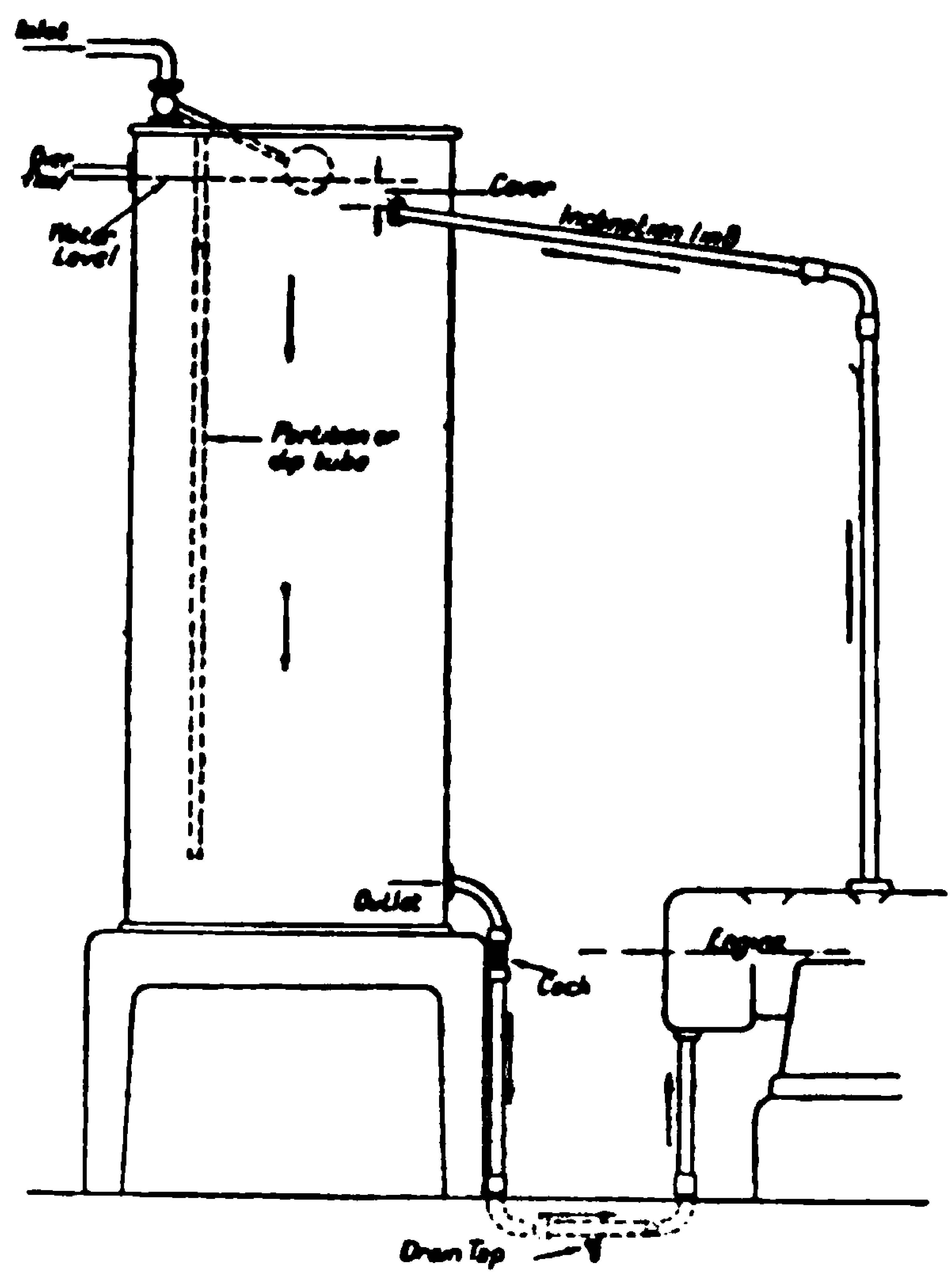


Fig. 49.

Single Cooling Tank Arrangement.

reason it is often erected in the open, with circulation pipes passing through the wall to the engine. In the sketch (Fig. 49) of the simple tank arrangement shown the amount of cover is usually about 2 in.

A positive circulation of water is often supplied by a small impeller or centrifugal pump driven by the engine, particularly if a small, compact engine is aimed at, in which case the tank may be replaced by a radiator and fan of the motor-car type. In many installations sufficient fresh clean water is obtainable to enable a tank to be dispensed with. The cooling water may be pumped by the engine or taken directly from the local water supply mains. In such a case the outflow from the jacket is always made visible, so that the quantity may be seen and possible stoppage of the supply noted instantly. A water outlet temperature of about 150° F. (maximum) to 120° F. (minimum) may be taken as a guide to securing the best engine efficiency.

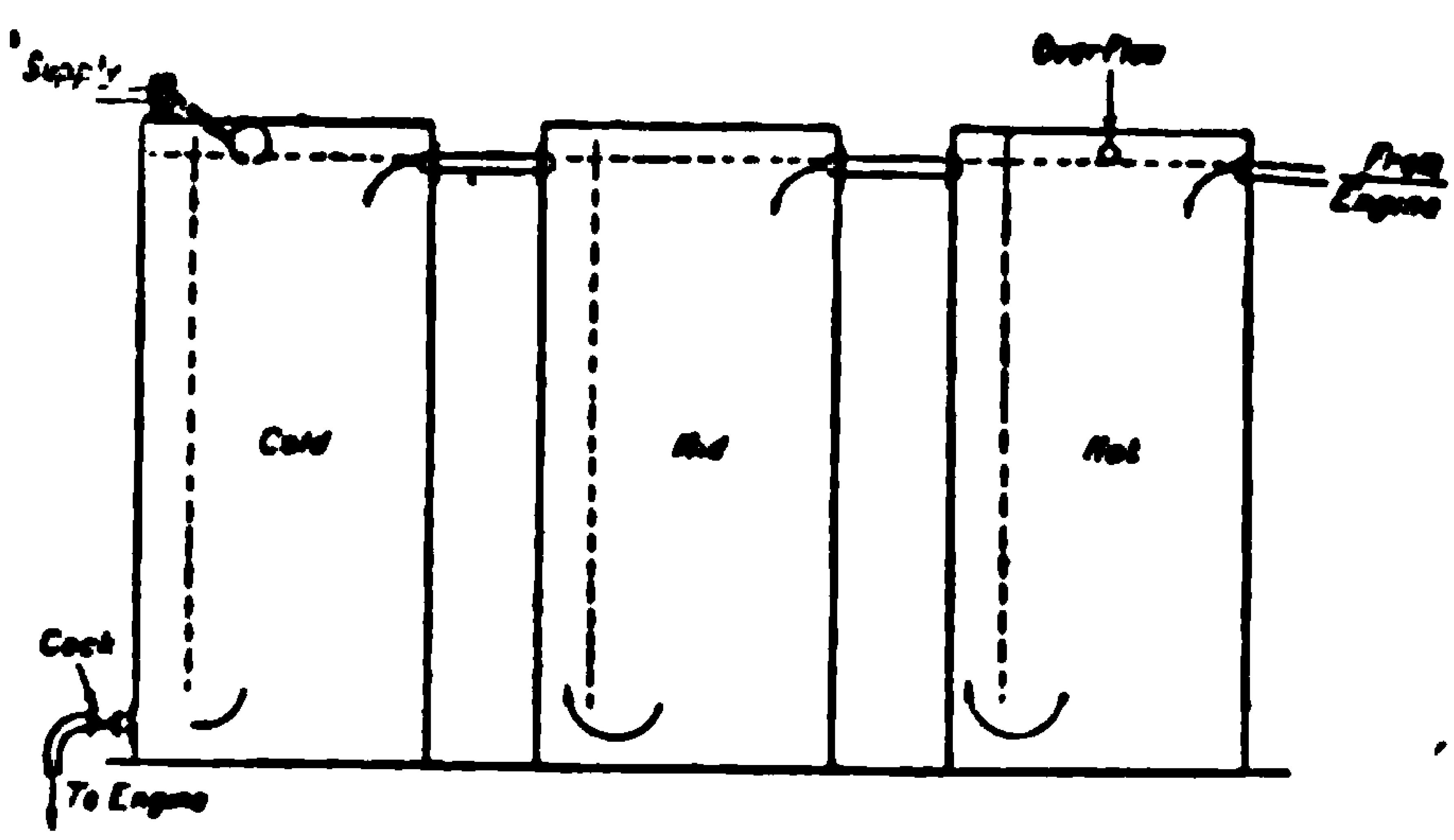


FIG. 50.
THREE COOLING TANKS IN SERIES.

The same general arrangements are shown in Fig. 50, which represents the interconnections when two, three, or more tanks are used in series. It will be noticed that the connecting pipe to each tank is made larger than the inlet, so that no retardation of circulating water may take place. The dip tubes or partition diverts the water immediately to the bottom of the tank. In large sizes of engines it is not uncommon to have a series consisting of a considerable number of tanks coupled together, and then, as the circulation becomes slow, a pump is often provided to boost the circulation. Sluggish circulation may cause the jacket water to boil. In some large plants using as many as fifteen tanks these were arranged in three sets of five, as it was found to give much better circulation than when the tanks were connected in series. Such an arrangement

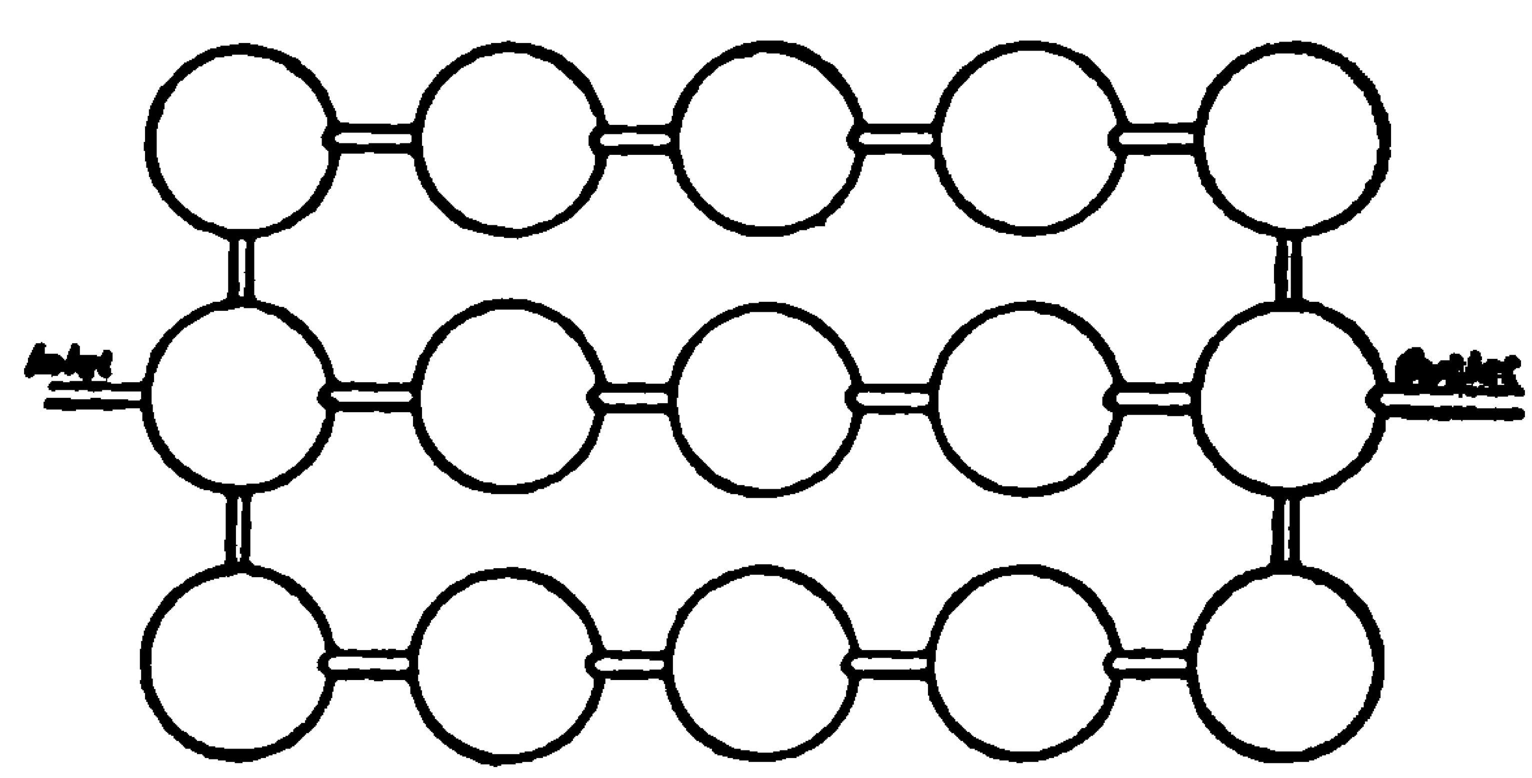


FIG. 51.
FIFTEEN TANKS SHOWN IN SERIES.

is shown in plan (Fig. 51). Almost one-third of the heat supplied by the fuel is removed eventually as a loss in the jacket water.

If the engine is exposed to frost, the water must be kept from freezing by means of an oil lamp under the cylinder or by running the water out of the jackets. Before running the water out of the cylinder jacket the ball-cock on the top of the circulation tank should be tied up, and the main supply cock as well as the cock on the cold water circulating pipe near the tanks should be closed. The water can then be run off by the drain cock. This drain cock is also used in cleaning out water passages. Sometimes a special non-freezing solution is used for jacket water.

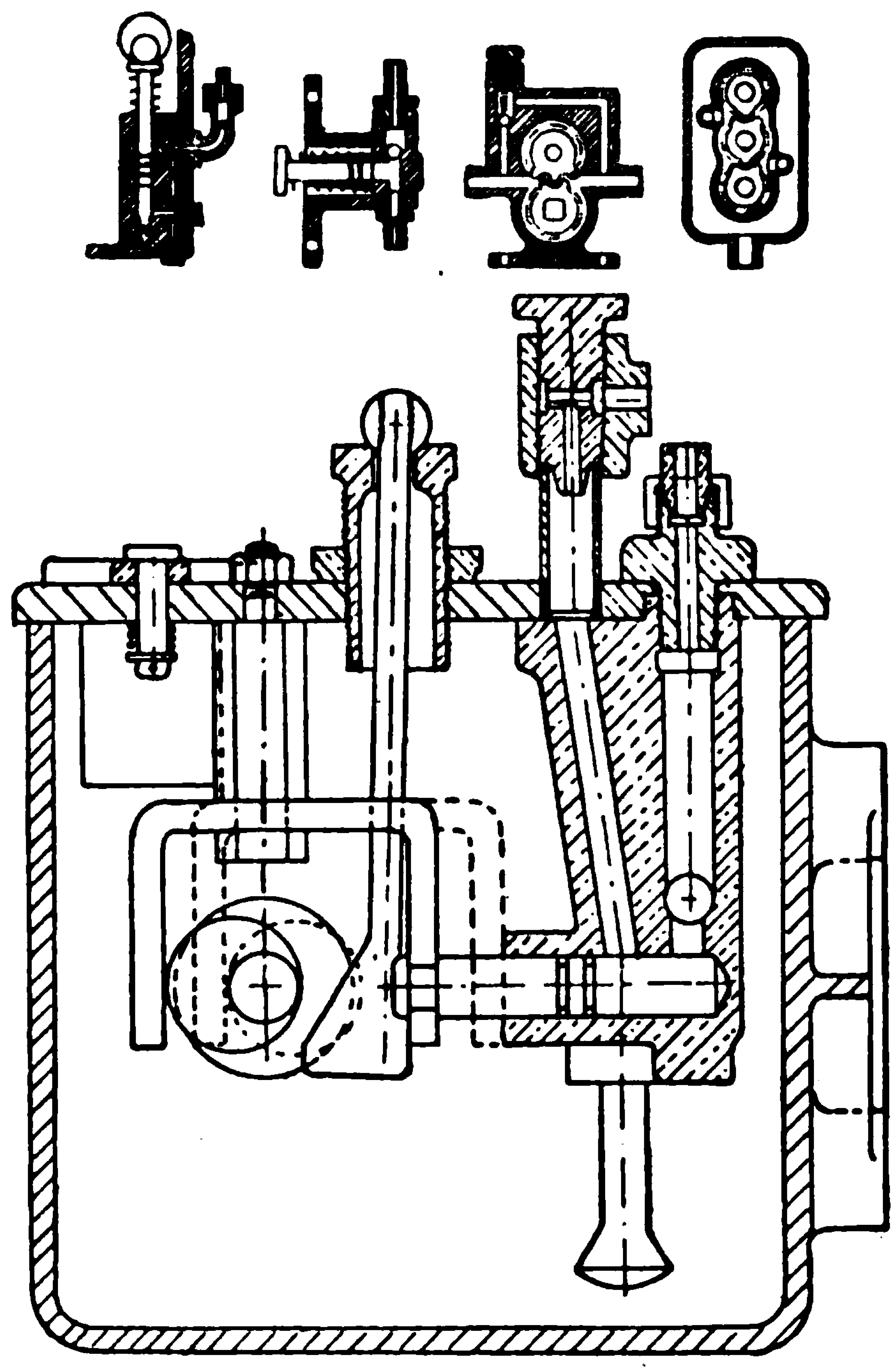


Fig. 52.

Diagrammatic Sketch of Gear, etc., Oil Pumps.

Lubrication Systems

These are too numerous to admit of description. The cylinder is a most important part, requiring special and separate lubrication. Engine makers supply the oil to be used in their cylinders, and the attendant would be well advised to keep to one good class of lubricant. An inferior oil will cause more trouble than a slightly inefficient supply of good oil; still it is poor economy to grudge the cylinder its correct supply. Some form of drip, sight-feed lubricator is usually fitted to the engine in such a position that the attendant can always watch its working. Bearings are fitted with oiler rings, and these have been shown in Fig. 25. The gudgeon pin is generally lubricated along with the cylinder. The crank-pin lubrication is

often by a syphon wick on the brasses, or by a drip feed into a banjo ring on the crank web. Layshaft and valve mechanism must be oiled by the attendant. The small oil holes in the rocker levers, etc., are left for the daily oil can, and they must not be forgotten.

Oil grooves are provided in all bearings by the makers. These are very important, and the design ought not to be changed. The attendant will see that these lead away from the main supply to the bearing in a diagonally outward direction, and with the direction of the journal movement. If the oil grooves are carried quite to the

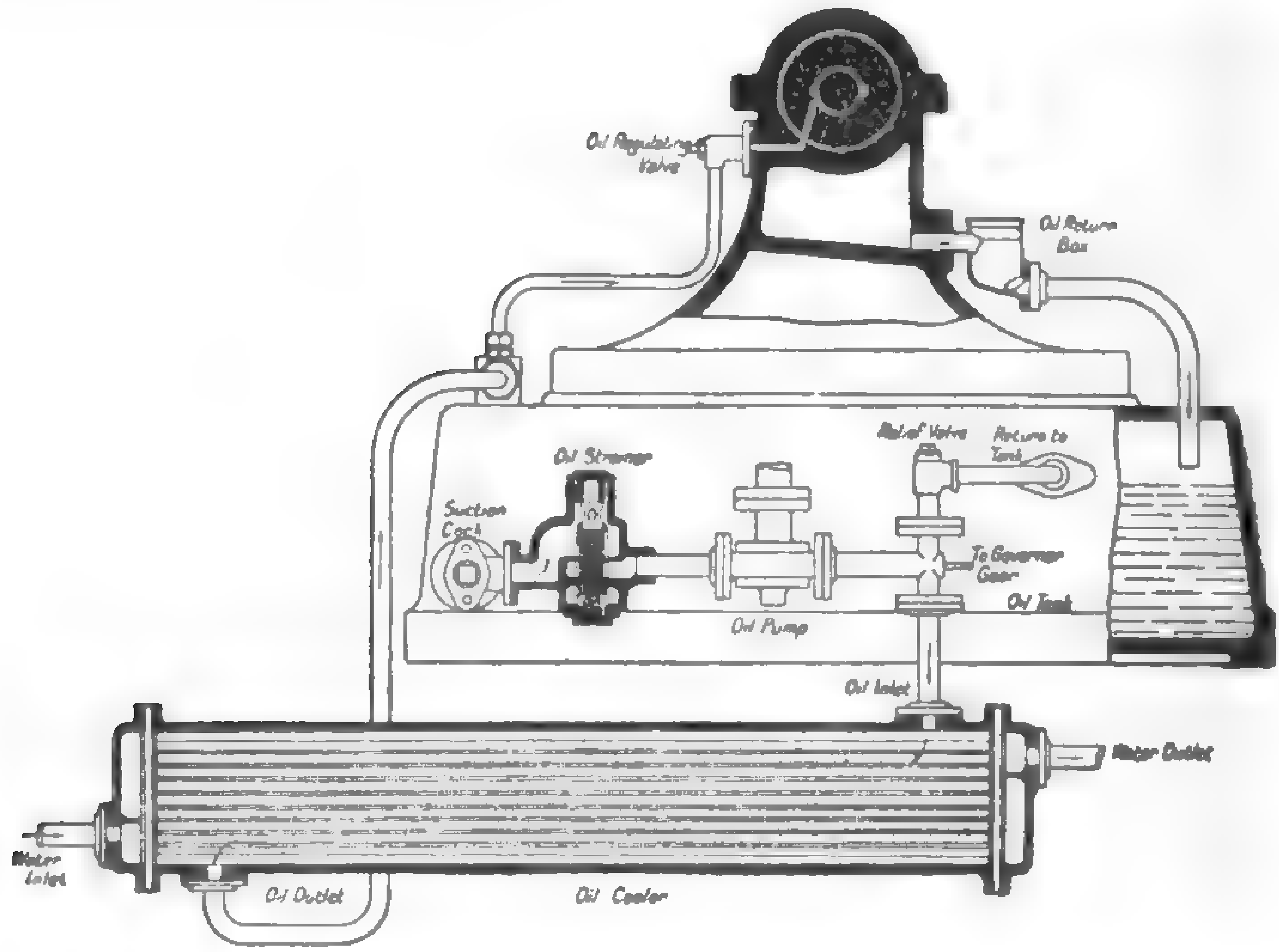


FIG. 53.

DIAGRAMMATIC ARRANGEMENT FOR OIL COOLING AND STRAINING.

ends of the bearing surface, there is a tendency for some oil to squirt out of the bearings; this is a loss. An attendant, when deepening the oil grooves, should endeavour not to change the design. Oil grooves and conduits must be cleaned out occasionally; copper tubes are generally used for conduits, and care must be taken not to have them flattened.

With forced lubrication a small pump, either of plunger, gear-wheel, or rotary type, is used. The latter is not employed to any great extent. Diagrammatic sketches of these pumps are shown in Fig. 52. The attendant should have no difficulty in tracing the oil

circulation system for any engine, nor should he have difficulty in recognising the use of pressure gauges, tell-tales, filters and strainers. There is always a certain amount of oil evaporation taking place, and this waste must be made up, the amount varying from ½ pint to 1 pint in each working week. This fresh oil is added through the main bearings. Later, in the chapter on Running In, the question of lubrication will be dealt with more fully. The used oil must be filtered or strained and cooled. A diagrammatic arrangement is shown in Fig. 53.

Lubrication of the oil engine working on the two-stroke cycle is even more important, if that could be possible, than it is in the case of the gas engine. The thrust is always downward, and not alternating, as in other engines. This makes the oil film between the wearing surfaces much more difficult to maintain.

CHAPTER VII

THE GAS PRODUCER, PRODUCER GAS AND FUELS

THE ordinary type of producer used for power gas is of the suction type. Pressure producers are used chiefly for gas heating rather than for power purposes. In principle these producers are quite similar, and such small differences in detail as there are may be readily followed. Both bituminous and non-bituminous coals can now be burned in producers, but the use of the former class is of more recent development. Coke and wood and some kinds of peat may also be used, so they provide a means of utilising poor, cheap fuels which would be quite unsuitable for steam raising.

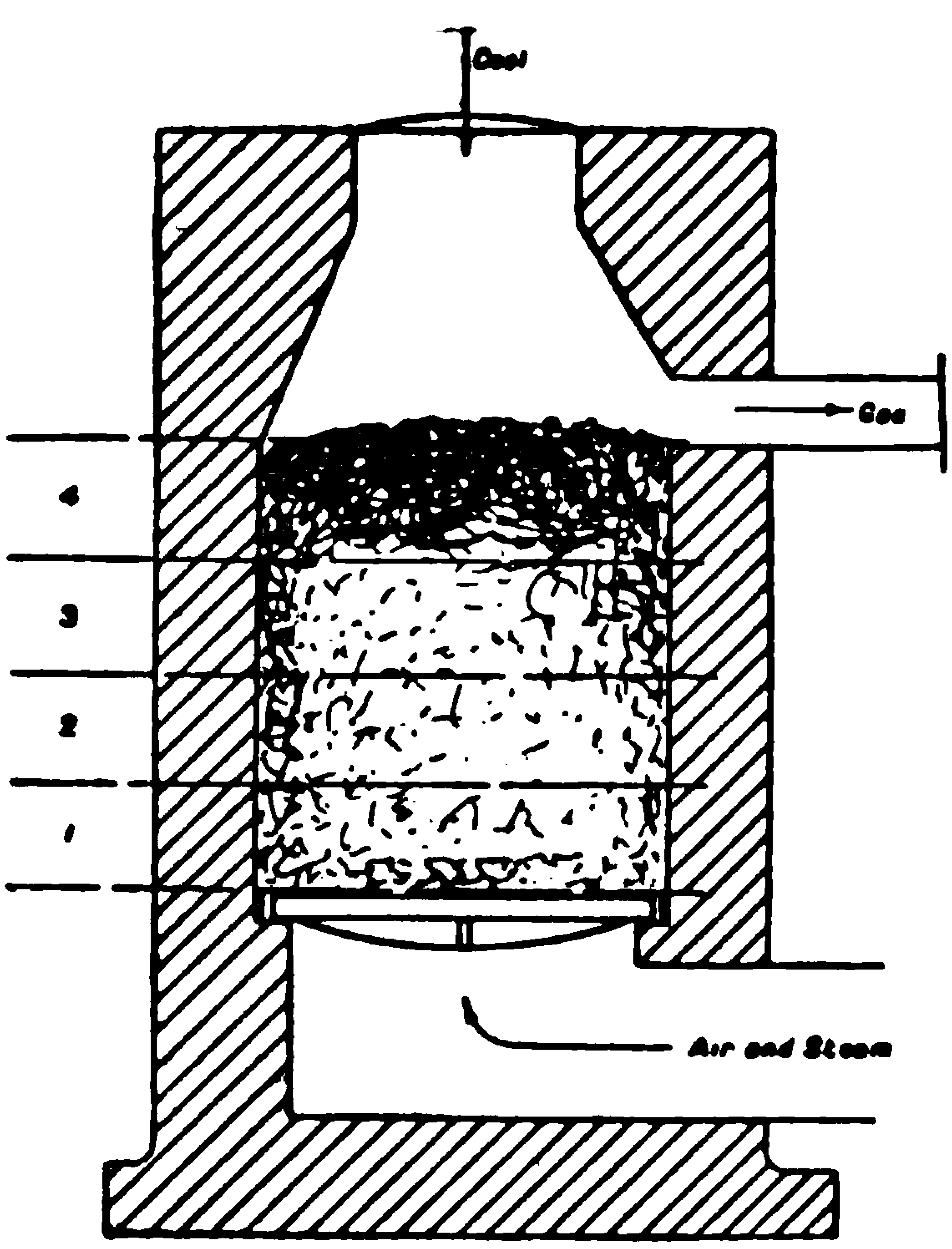


FIG. 54.
SKETCH SHOWING PRODUCER ZONES.

The producer fire is contained in a deep firebrick-lined cylinder, and is supported on a bottom grating. The ordinary steam boiler fire is a few inches deep; the producer fire depth may run into feet in certain designs. In the case of a producer burning anthracite peas the fire is about 30 in. in depth, while with larger pieces the fire depth is about 48 in. This makes the producer very large.

The fuel bed of a producer is divided into four parts or zones. These are—(1) ash; (2) combustion; (3) decomposition; (4) distillation. The second portion is where the actual work is carried out. The sketch (Fig. 54) gives some idea of these zones. Fresh fuel is added from the top. Air and steam enter by the grating, and the gas leaves near the top, but to one side, as shown. Zone 1 will consist, in general, of ash, since the cheap fuels used have a large amount of

ash. Zone 2 is the combustion zone, where the oxygen (O_2) of the air and carbon (C) in the fuel burn completely to form carbon dioxide gas (CO_2). This corresponds to the usual glowing furnace fire, where complete combustion takes place round about 2000° F. In zone 4 the fuel is subject to the very hot gases from below, and all the volatile part of the coal is distilled off. It cannot burn, since the oxygen of the air has been used lower down. These distilled gases, mostly hydrogen or methane, have a high calorific or heat-giving value, and greatly enrich the gas produced. The remainder of the fuel—the non-volatile or carbonaceous part, now glowing hot—forms zone 3, in which the carbon dioxide (CO_2) from zone 2 takes up more carbon

$$(C + CO_2 = C_2O_2 \text{ or } = 2CO)$$

to form carbon monoxide, which, of course, is a good burning gas, since it will form carbon dioxide (CO_2) again whenever it can get the necessary oxygen. In this zone also the steam, supplied with the air, is broken up. The high temperature and contact with the glowing carbon reduces the steam (H_2O) to carbon monoxide and free hydrogen (H_2), both of which are good burning gases. It will be seen that if oxygen and steam are supplied a good gas, rich in CO and H_2, would be obtained. Unfortunately for combustion, air only is available, so the large percentage (79 per cent.) of nitrogen, the inert gas in air, dilutes this down to form a gas very much poorer in quality than town gas, although still richer than blast furnace gas.

There is no such sharp division between the various zones as is shown in the sketch; each one merges into the other. The presence of CO_2 in the gas is undesirable, since it represents completely burned carbon, and is of no further use for heat or power. A certain amount is unavoidable, and depends largely on the temperature of zone 3. If this falls too low, the CO_2 is only converted to CO with great difficulty, so that a high temperature is desirable for production of the preferred CO and for reduction of the CO_2 content. This is readily obtainable if the supply of steam is cut down, for it is the breaking up of steam into oxygen and hydrogen which steals the heat and lowers the temperature. Reduction in steam quantity has its evils too, so that, as usual, a compromise is necessary. If insufficient steam is supplied, the hydrogen, even more valuable than the CO, is reduced in quantity, and, more important still, the temperature becomes so high as to form clinker of an extremely objectionable kind, which has to be chipped out, and generally destroys the fireclay lining in the process, since it has a habit of forming there first at a definite level, and growing upwards until only a small opening is left for the draught. Another point favouring good gas is the use of

small fuel and fairly slow blast through the producer. Coke and anthracite are generally best—about $\frac{3}{4}$ in. to 1 in. cubes; if much smaller fuel is used it interferes with the draught.

Anthracite is not generally stocked by the ordinary coal dealer, and must be carefully watched for quality when ordered, as it is often mixed with bituminous coal. The attendant is often required to state the approximate amount of fuel in stock, so it may be stated here that when anthracite is broken small it weighs approximately 58 lb. per cubic foot. The calorific value varies from 15,000 to 15,500 B.T.U. per pound, and analyses show: Carbon, 90 to 93 per cent.; hydrogen, 4 to 4·5 per cent.; oxygen, 3 to 5·5 per cent. Anthracite is clean to handle, safe to store, gives off no dangerous vapours, and is easily worked in chutes.

Gas coke is more bulky than anthracite. It has already been subjected to one distillation, and therefore any volatile constituents are hard to deal with. It contains much more sulphur than anthracite, and the remaining ash is nearly twice as much, say 5·8 per cent. of fuel burned. The calorific value is about 13,500 B.T.U. per pound. Ordinary analyses show: Carbon, 88 per cent.; hydrogen, 0·02 per cent.; oxygen, up to 3 per cent.; while the weight per cubic foot is 34 lb. Its one advantage is that it is cheap and plentiful. In working the coke a large quantity of steam is required.

It was stated that peat could be used. This is best when compressed into briquettes and afterwards dried to drive off moisture and volatile material. After this it forms a good producer fuel. The gas given off requires little scrubbing, is clean, and has a high calorific value. It is also a cheap class of fuel.

In maize-growing countries the maize cob can be used as a fuel. Straw has also been used in Western Canada. These notes are only to show that from almost any combustible material the producer may be made to give a gas suitable for gas engines. The attendant knows, however, that even with an inferior quality of coal it is difficult to keep an engine working at nearly constant full load, and fortunate is he who is kept supplied with good anthracite.

Pressure producers customarily have a small steam boiler for producing the necessary steam, which, under slight pressure, is also used to blow in the air. A gas-holder is also used for storing the gas. Leaks must be very carefully guarded against in the pressure system, since CO is an extremely poisonous gas, having no smell to give warning of its presence. Leaks in a suction gas producer, where the draught is due to the engine suction only, allow air to enter, hence lowering the efficiency, but they are not dangerous.

In suction producers the steam, as a rule, is generated by heat in

the hot gas leaving the producer. Some makers also cause the air to be pre-heated in the same way. This tends to efficiency, and also cools down the gas before it leaves to go to the purifier, where it is further cooled and cleaned of dust and tar before going to the engine. The purifier, or scrubber, is generally a sheet metal tower containing coke which is constantly sprinkled with cold water. The gas passes up through this, then finally through a thick layer of sawdust, and thence to the engine.

It will be well now to consider the actual gas producing plant, and in Fig. 55 is shown a gas producer of good design suitable for working with an engine of 40 to 50 brake horse-power. The height marked on the sketch gives some notion of the actual size and proportion of the scrubber in relation to the producer. A producer of this type depends entirely for its satisfactory working on the care and attention given by the attendant. It has no moving or mechanically operated parts. When the fire is lighted, fuel is fed into the producer by the attendant until the hopper is full, and then the rotating valve or double-door arrangement is used to drop fuel inside the producer. As was seen from the elementary description, only a thin layer of the fuel is burning at the bottom, the remainder of the fuel above this being exposed to the full heat of the fire, while all hot gases are drawn up through it. This is the best method that could be adopted to get rid of volatile constituents in the fuel as these distil off, but they must be extracted from the gas, or the engine would become gummed up. It is clear then why the large scrubber, using 1½ gallons of water per brake horse-power per hour, is required. Gas must be perfectly free from tar.

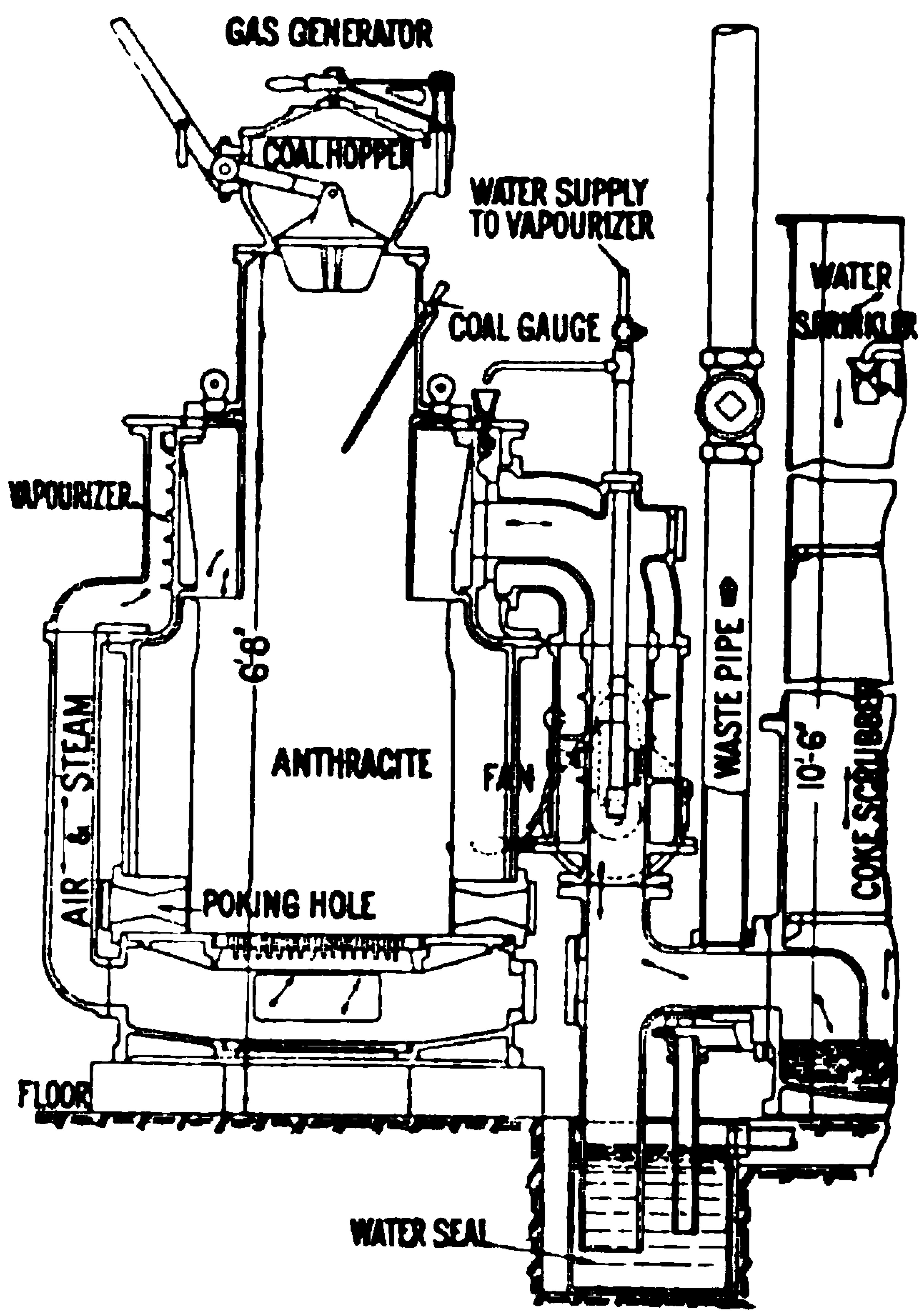


FIG. 55.
PRODUCER.

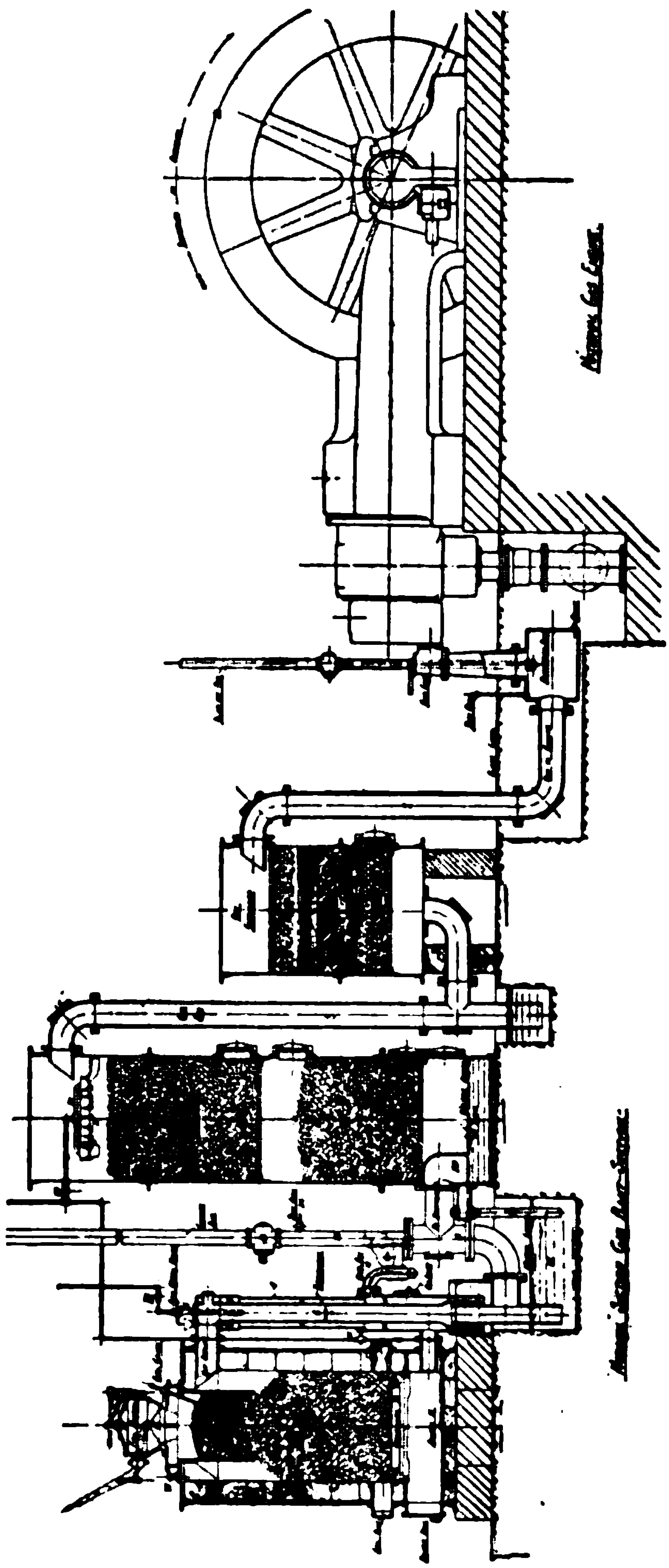


Fig. 56. Producer Plant.

As the fuel is consumed a layer of ashes is deposited on the bars, which, unless periodically removed, deadens the fire, and the production of gas falls off. To remove these ashes a fire door has to be opened so that they may be raked out by the attendant, and this must be carried out quickly, or air will enter which may stop gas production or cause an explosion in the producer. The deep bed of fuel tends to burn hollow and stop full gas production. If this hanging or scaffolding is knocked in by the attendant, the resultant disturbance generally destroys the production of gas, so the engine would be inclined to slow down and stop, and the producer must be fanned up to get it working again. It is through small holes that the poking down has to be carried out. These holes are plugged during working conditions.

A good attendant knows that to leave the air-lock doors open when charging would lead to great danger and stoppage. Some producers are made so that this cannot occur, the closing of one door being made to open the other. With the fuel fed in this manner it is quite obvious that at one time there is a great amount of fuel in the producer and at other times too little.

There is no connection between the fuel fed into the producer and the work that is being done at the engine, and therefore the quality of the gas is variable.

Water supplied to the producer to form water vapour plays a most important part in the gas manufacture. The control of the water is generally left to the attendant, who regulates it without anything except his own practical experience to guide him as to quantity required, though in one or two designs the suction of the engine is made to control the feed of water; but even this latter method is not very definite in its regulation. From the foregoing it can be readily understood that changes in staff are not much desired where gas producer plants are to be used for getting full power from engines.

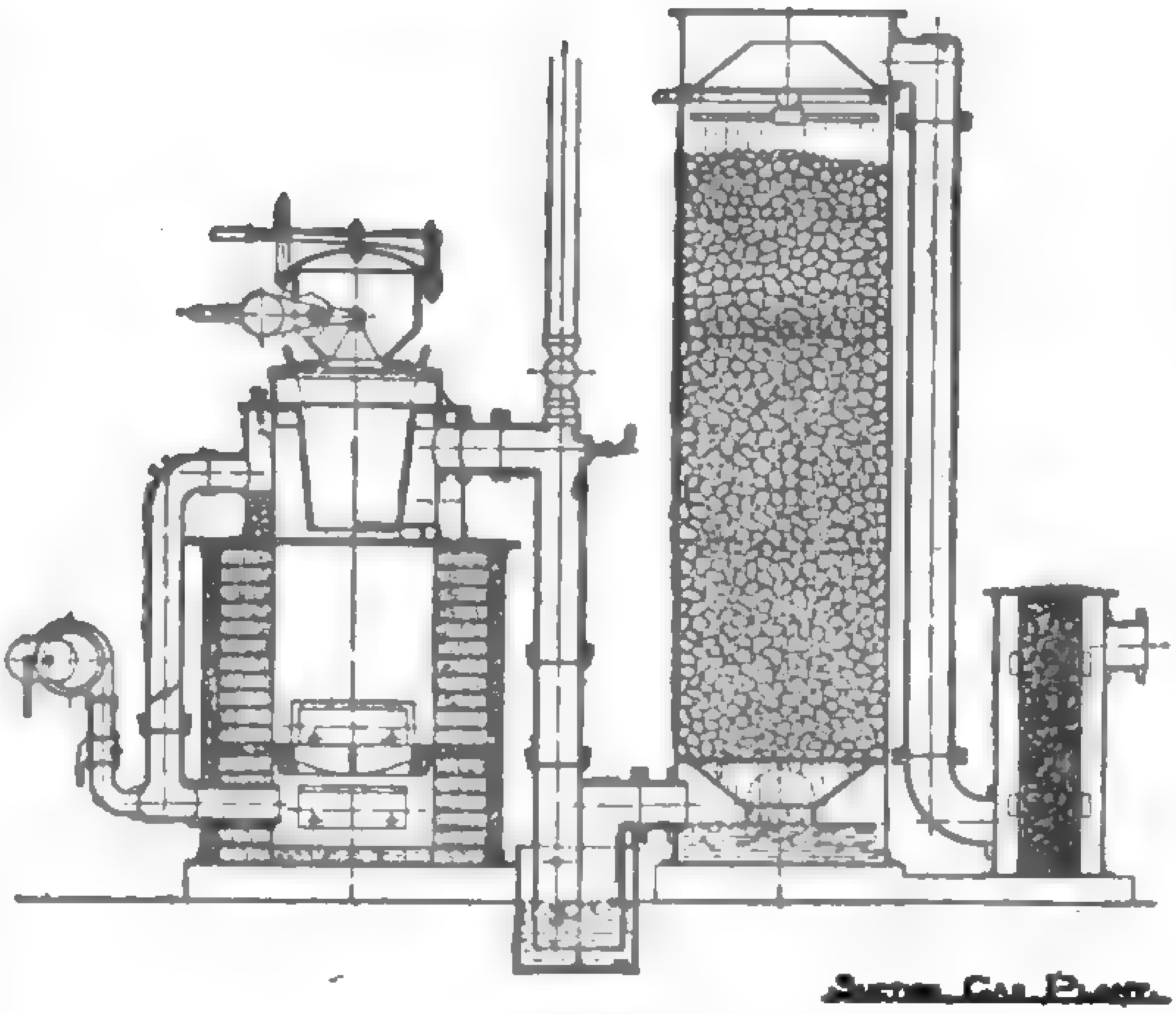


Fig. 57.
Producer Plant.

Even with the greatest care, and when working on a steady load, air is being drawn over the surface of the water in the vaporiser and takes up a certain quantity of steam. If the load should be suddenly increased by throwing on a heavy machine, more air would pass over the water, but no increase of steam would be available. Usually there is a tendency for the water to cool down, and the amount of steam decreases. The gas would therefore be of lower quality; the engine would not give the same power, but would slow down and stop. The fire cannot, therefore, respond rapidly, and this is why gas-holders have to be introduced if the best efficiency has to be obtained from plants which are working other than at full loads.

In selecting a producer plant it is advisable to have one larger than is actually necessary for present requirements. Then as more power is required the engine may be replaced by one of larger size. One often finds that the producer is not large enough to obtain full

power from the engine if the fuel is not of the very best unless the producer is working at its very limit. In fact, little provision is made for alteration in quantity or quality of gas, and this precaution in gas plants is of most vital importance, neglect of which causes much worry.

The sections shown of the "National," "Fielding," and "Mond" producers require little description. When the engine and producer are working the engine sucks in a charge of gas from the expansion box. This causes a flow of gas from the scrubber, and from the producer to the scrubber flows the gas made by partial combustion of the fuel in the furnace. The gas which comes off at the upper part of the producer gives up its heat and helps to vaporise the water required for the steam supply. The main parts in all producers are: the hopper, coal container, vaporiser, firegrate, gas pipe, hand or motor fan, water seal, coke scrubber, water sprayer, and gas supply pipe with expansion box. In connection with the Mond producer there is such provision made that the hot outgoing gases highly superheat the incoming air for blast travelling in the reverse direction. According to Dr. Mond, this blast air must be super-saturated with steam before introduction to the combustion zone. By-products plant is fitted in conjunction with all large producer plants, but this valuable side-line cannot be treated in this work.

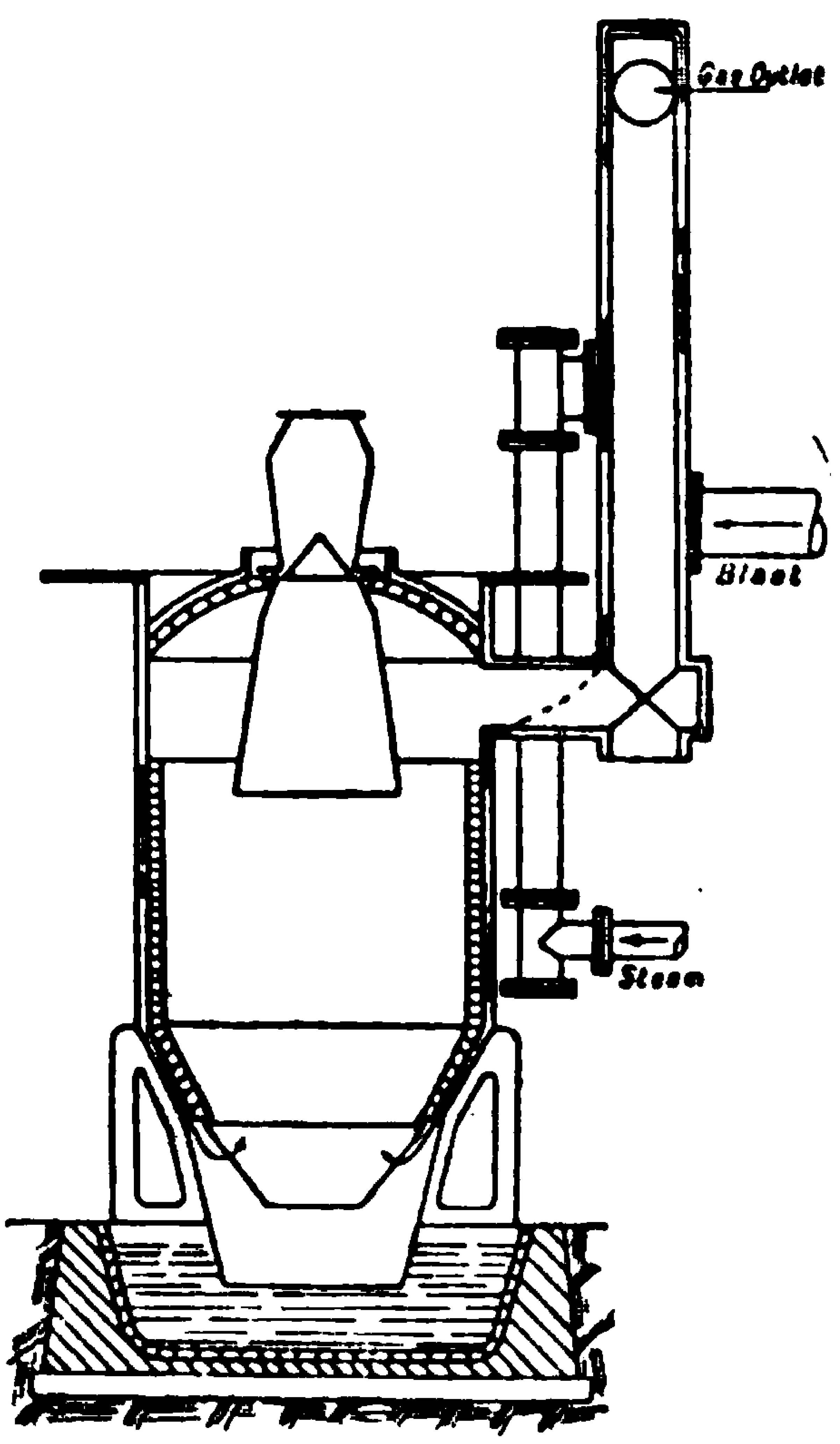


FIG. 58.
PRODUCER PLANT.

Blast furnace gas, after it has been treated in the chemical branch of the ordinary ironworks plant, can be used for rolling mill gas engines. On the Continent blast furnace gas has been more extensively used than in this country, where the gas is chiefly used to raise steam.

Bituminous coal requires a special form of producer to cope with the tar and soot which appear on cooling down the distilled gases. Broadly speaking, two methods are used. The tar and soot may be separated out mechanically after coming from an ordinary producer. The more general type, however, causes these gases, when first distilled, to pass through the hottest part of the fire, where they are

further broken up into fixed gases, the tarry and sooty constituents being burned, the soot to CO, as in the case of the rest of the carbon. The available heat is by this method retained in the gas, although the separation of tar for chemical purposes might prove quite a valuable feature if the plant is large enough to make it a saleable by-product. The scrubber plant is somewhat more elaborate in the bituminous plant, a wood grid scrubber with sprinkler being first introduced, or frames of corrugated sheets having a large number of small holes through which the gas must pass and be washed by the water. The drawing (Fig. 55) shows how the gas leaves at the side of the producer, air and steam from the vaporiser ascending by the grate as usual and extra air coming in with the fresh fuel from above. The bituminous coal thus made available is very much cheaper than anthracite otherwise used.

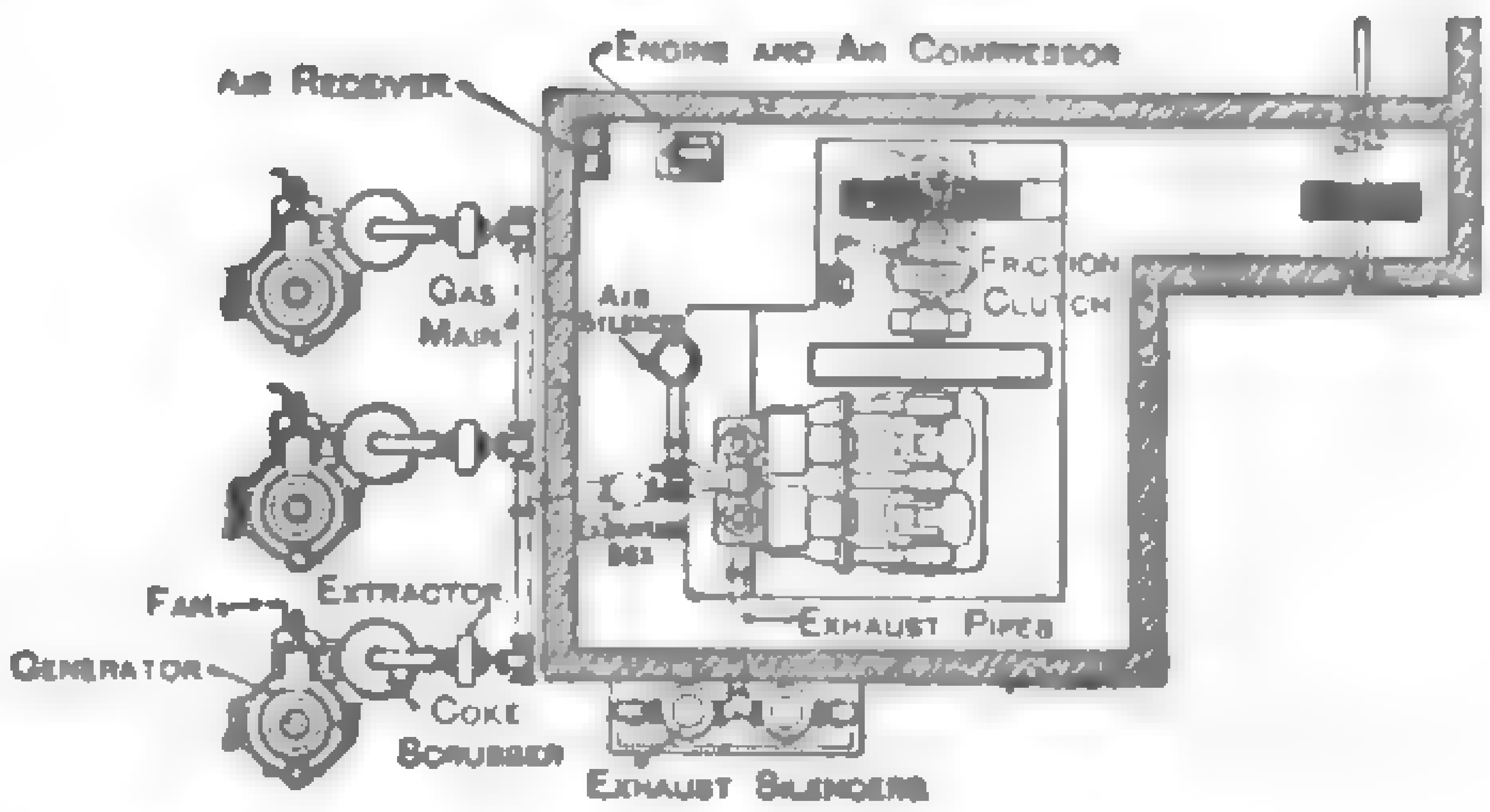


Fig. 59.

Arrangement of National Gas Engine.

A sketch plan of a "National" gas engine and suction gas plant, showing the relative positions of engine and producer, friction clutch wheel, and driving pulley on shafting, is shown in Fig. 59. This sketch shows three producers connected to one gas main and engines, which are rated at 300 brake horse-power at 200 revolutions per minute. It will be noticed that there is plenty of space around the producers and scrubbers for inspection. As it is not intended to revert back to gas producers, the attendant might note that to ensure that the maximum quantity of carbon monoxide shall be obtained in a producer it is advisable that :

(1) The temperature of the fuel bed should be high—something between 2100° F. and 2190° F. ;
(2) The fuel should be porous and of small size ;
(3) The blast pressure should be low and speed of passage of the blast through the fuel should be slow ;
(4) The fuel bed should not be too thin.

Fuels for Oil Engines

The class of fuel pre-eminently suitable is a somewhat light and partially refined, or semi-crude, oil, which, owing to smaller demand,

need not be any dearer than the residual or "fuel oil." This class includes "gas oils" and "solar oil," and is used almost exclusively throughout Europe. The lighter petroleum products, such as

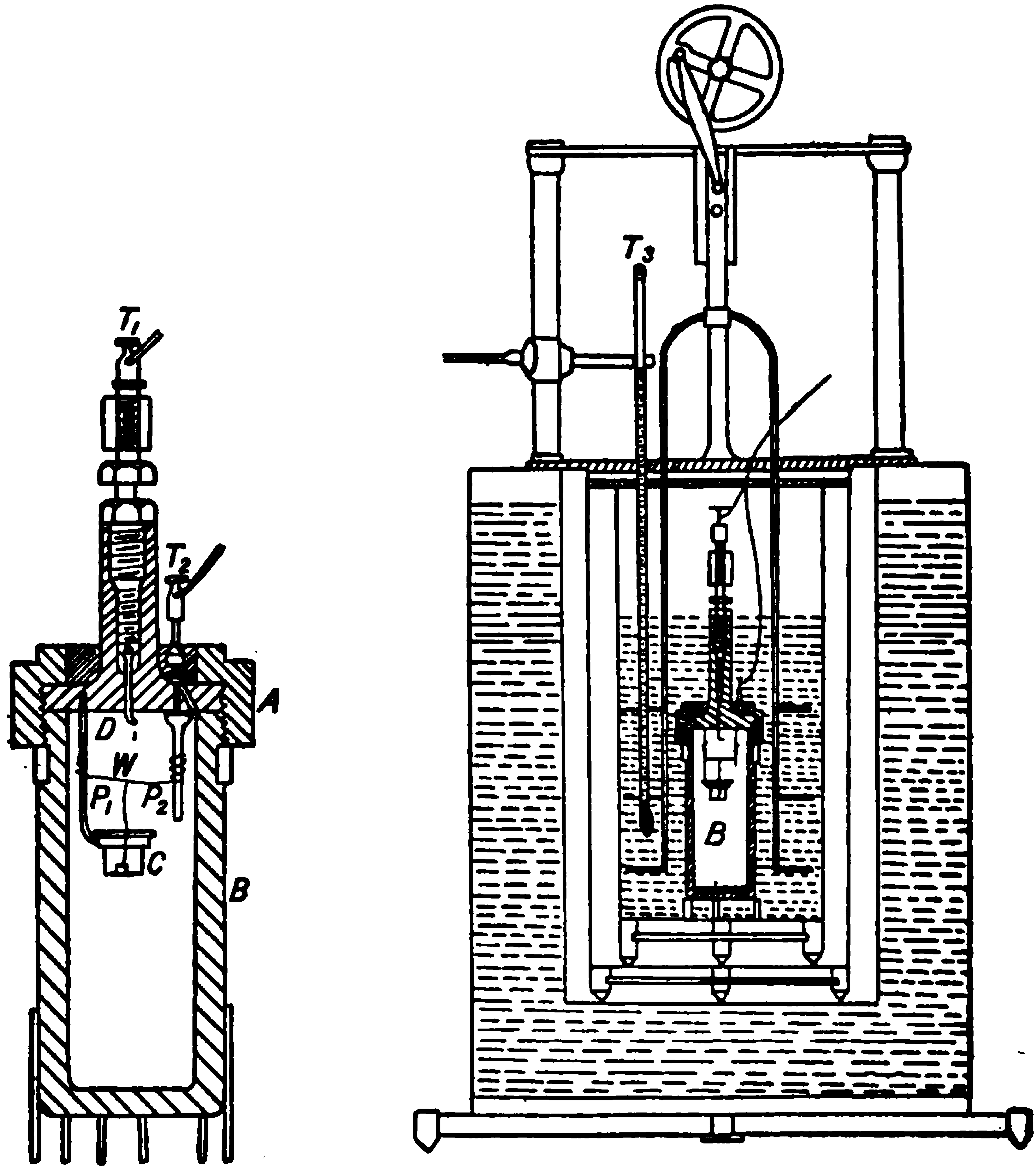


FIG. 60.
BOMB CALORIMETER.

paraffin oil, are sometimes used for small engines, but have no advantage except that they may be more readily obtained at short notice in out-of-the-way places. They have also the disadvantage of greater fire risks, since they are much more inflammable, and, of course,

they are more expensive. In all cases the makers are only too willing to advise as to the suitability or otherwise of a proposed oil. A low sulphur content is desirable (not greater than 0·5 per cent.), particularly where water injection is used, to avoid corrosion due to the formation of acids. The ultimate composition of oils does not vary greatly; about 84 per cent. carbon and 12 per cent. hydrogen is quite average.

It is unusual to find any appreciable amount of water in the oil, but when any does find its way into the fuel supply lines it interferes very quickly with steady firing, and may even stop the engine. If a little of the fuel is sprayed on some oily surface, such as a tank or a cylinder jacket, any water present will appear in characteristic globular form. Filters and sumps are customarily fitted to allow water to separate out. Such fittings require frequent cleaning.

A fuel oil specification usually consists of a set of figures which the attendant would do well to consider and learn what the terms employed really mean. The most common of these are "flash point," "viscosity," "calorific value," "cold test," "coke test," "sulphur," "ash" and "sediment" tests. The calorific value obtained by the bomb calorimeter is to-day accepted as the standard. A sketch of the bomb calorimeter is given in Fig. 60. This test provides a degree of accuracy which is adequate for all purposes. The apparatus consists of a strong metal cylinder *B*, the cover *D* of which is held down by screwed cover *A*. Fixed in the cover *D* is a carrier *P*. The left-hand view shows this clearly, and it will be seen that the platinum wire *W* leads to the fuel to be tested. T_1 and T_2 are the terminals which are attached to the battery supplying the current of electricity which ignites a known weight of fuel under test. A thermometer T_3 measures the rise in temperature, to the nearest $\frac{1}{1000}$ of a degree, which takes place in the water which surrounds the bomb *B*.

Cold test is useful as setting a limit to atmospheric conditions under which an oil can be handled. The coke test involves a method of introducing a distilling process, and is a very useful guide for determining the coking characteristic of any fuel which is to be burned in an engine cylinder.

It must be remembered that oil in a liquid form cannot be burned. Oil fuel is burned in the cylinder of an internal combustion engine only after it has been changed to a gas. The usual quantity burned is ½ pint per brake horse-power per hour for engines from 30 to 150 brake horse-power. Oil has a specific gravity in the neighbourhood of 0·9, so that a pint will weigh approximately one pound.

CHAPTER VIII

INSTALLATION

GAS and oil engines should be placed where there is plenty of light and accommodation. A good engine-room makes for success. Engines placed in or near a smithy are very often under repair.

In all cases foundations are built before the engine is sent from the makers. The attendant may probably have to assist in making the foundations. Usually this foundation consists of a concrete of five parts of broken bricks, one part of cement, and one part of fine sand. It would be well to finish off the top and sides with one of cement to one of granite chips and smooth off the surfaces. In the case of oil engines this smooth surface is very necessary so that fine particles of grit may not get into the crank case and from there into the working parts. A wooden floor is to be preferred in an engine-room, as it is easily cleaned, is not slippy, and does not cause dust. Cement and stone floors become rubbed and pitted, leaving dust on their surfaces which, on sweeping up, gets into the working parts. Steel floors become very slippy and dangerous. The engine is placed in such a position that the exhaust pipes are short and free from bends, and at the same time full consideration is given to the direction of rotation of the engine when connecting up to the line shafting. A driving belt ought never to be crossed, and short driving belts are to be avoided.

It is usual for the makers, on supplying the working drawings of the foundations, to offer to supply the bolts or the drawings from which they can be made. From the drawings a template of the bolt positions is usually constructed. The bolts are set in position before the foundation is made. They should be surrounded by wooden boxes as shown in the foundation plan, allowing "play," so as to permit of any slight adjustment in bolt holes. Too great care can scarcely be taken with the foundation; it must never be smaller than that shown in the maker's blue prints, and a competent builder should be employed to construct it. Where the ground is soft, or near pits or drop hammers, the usual depth must be increased. The foundation should be given ample time to set. If this is not allowed for it may lead to noisy working and shaking of the engine parts.

The engine frame is levelled up by means of steel wedges, after which all is grouted up with cement. After the cement has set the wedges may be withdrawn and the recesses filled with cement grouting.

The foundation bolts are pulled down evenly all round. If a bolt has been overstrained it should be removed at once and a new one put in its place. The practice of heating up the body of the bolt before placing it in position, then screwing up and allowing the contraction of the material of the bolt to draw the frame on to the foundation, has led to many bolt failures. After all the bolts have been gradually and evenly tightened so as to avoid distorting the engine frame, the crankshaft is placed in position. The shaft is then turned in its bearings; free turning of the shaft is a good indication that the frame has not been twisted. It never pays to leave the bolting down of the bed-plate until each of the bolts can be screwed up very tightly without altering the freedom of the crankshaft or spoiling the level of the engine. An engine is levelled from some smooth machined part—not from the painted castings. The outer bearing, if one has to be fitted, must receive the same special care so that the alignment may be perfect. Crankshafts have been broken by badly lined-up bearings. If it is an old engine that is being replaced by a new one, care will be required in placing the engine so that the belt will run evenly and on the centre of the pulley on the shafting. In such a case, where the shafting has already been in use, the engine may require a slight alteration to enable the belt to work on the centre of the driving pulley. This last adjustment cannot be made after the engine has been grouted up. The grouting is best done by making a trough of clay round the engine frame a few inches clear of the casting. When the grout has hardened up, it may be chipped flush with the engine, or dressed off at an angle with the foundation. Grouting material is made by mixing equal parts of cement and sand moistened with water to run freely under the engine frame.

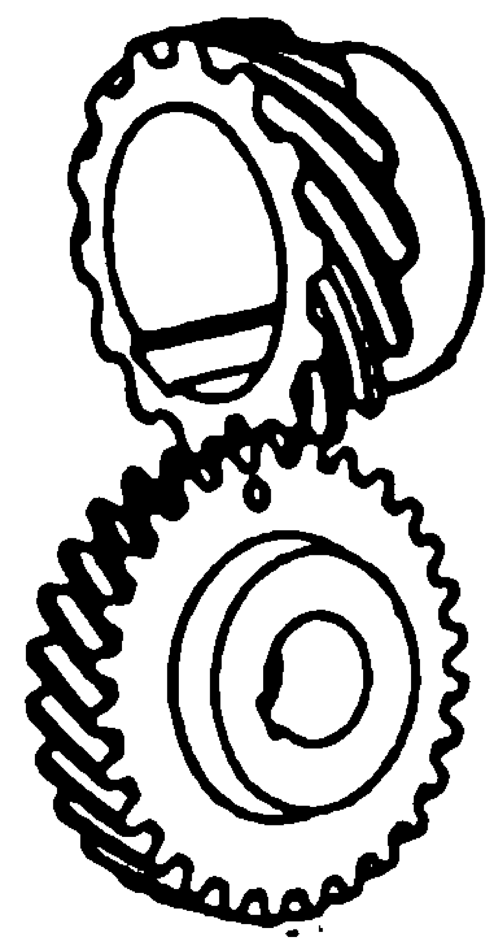
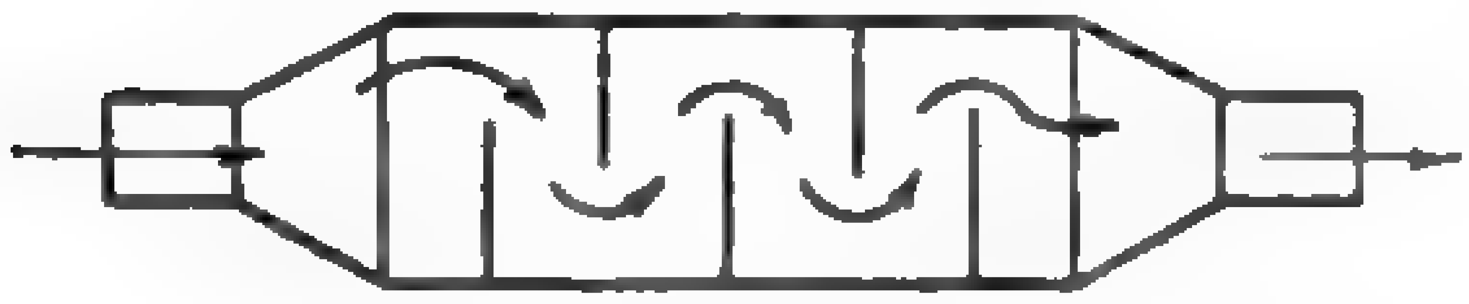
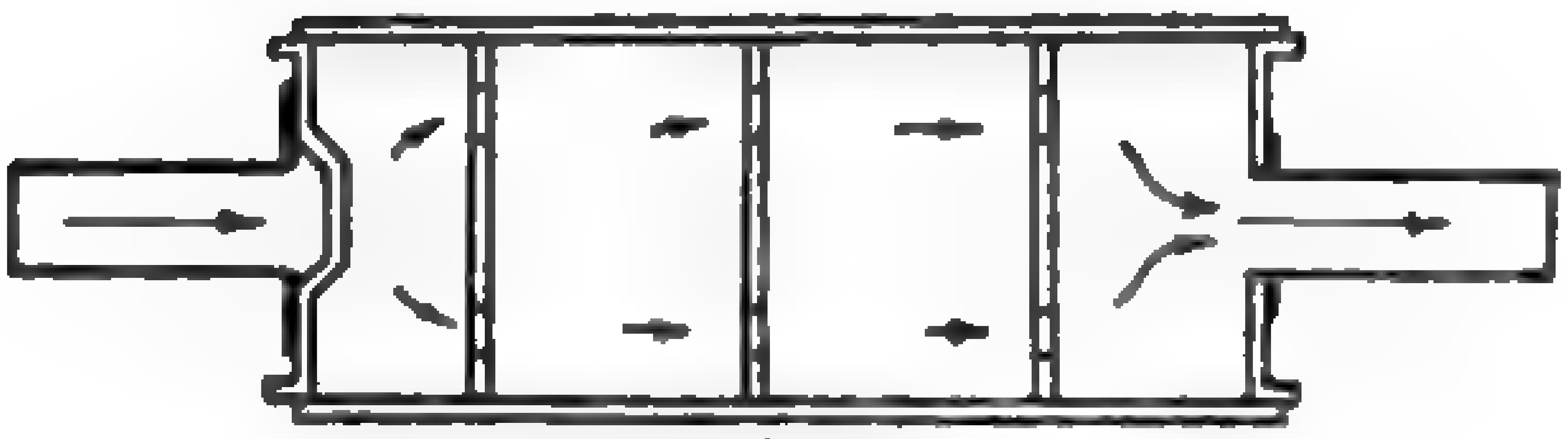


FIG. 61.
SPIRAL GEAR WHEELS.

If the connecting rod has been disconnected from the crankshaft during the process of lining up, the brasses should now be carefully cleaned and bolted up in position. The shaft should again be turned to test for freedom of working. Care must be taken when connecting up the layshaft to the crankshaft to have the proper teeth in the driving wheels mating. These teeth are usually marked with two ciphers, one on driver on crankshaft and one on driver on layshaft (Fig. 61). Neglect of this would lead to improper setting of the valves.

Gas and air supply pipes should be free from elbow bends. If bends are required, they should have a large radius, and the pipes must be of ample dimensions. They are usually placed in trenches in the foundations. All bends cause excessive back pressure, which does not make for economy, and may even lower the rated power of the engine, since the engine is constantly working against a load which accomplishes no useful result. If the exhaust pipes are long they should be connected to the exhaust box or expansion chamber near the engine. The exhaust pipes are fitted with flanges so that cooling water may be used. This also tends to act as a silencer, but too much water must be avoided. On producer gas the water should not be introduced near the engine, for, with a gas containing sulphur, a corroding effect is produced. Drains are provided so that this water may not find its way into the cylinder. Where the engine is to be insured, and also the building, too much care cannot be taken in keeping all combustible material a considerable distance away from the hot pipes. In the vertical pipe leading the exhaust to the atmosphere it is usual to place a tee drain at the bottom for drawing off water which may collect; the plug on the tee-piece may also be used as a cleaning door, enabling all soot and oil deposits to be removed.


(a)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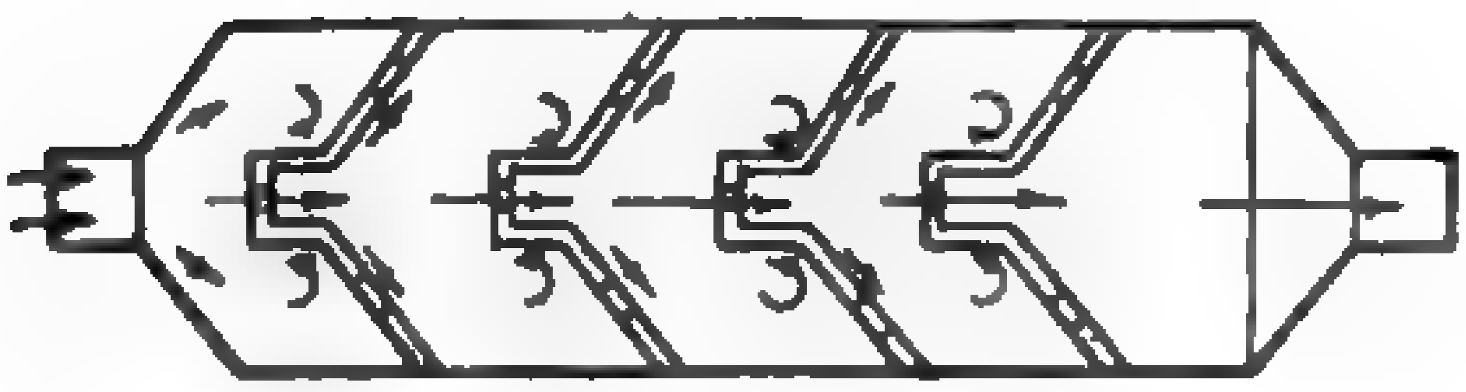
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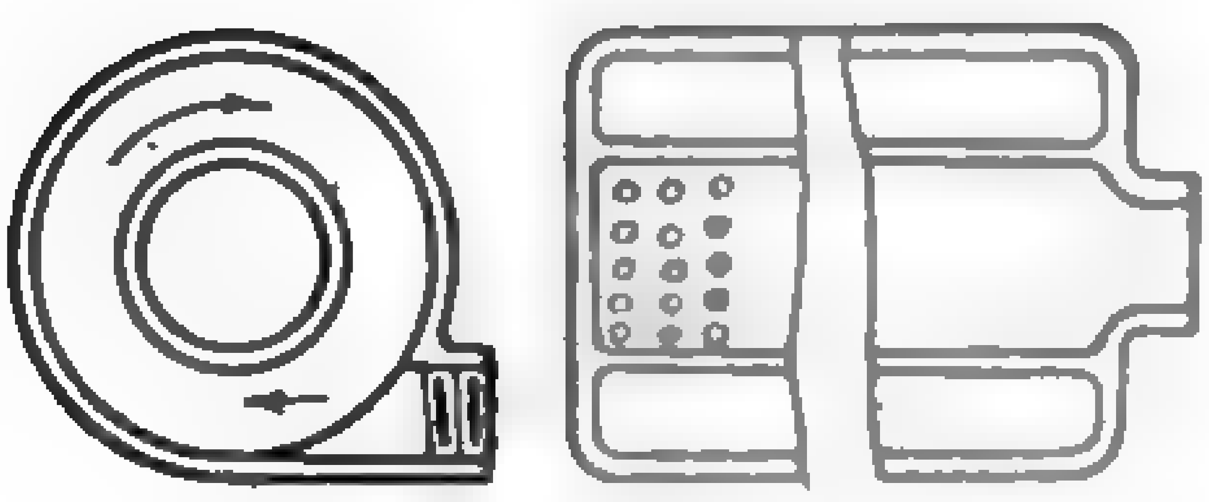
(d)

Fig. 62.
Silencers.

Small engines are provided with muffles or silencers which are placed in the open air in an accessible position for cleaning. Fig. 62 shows a few of the many mufflers or silencers which have been used. They must be kept clean, or a choking effect is produced which is equal to a reduction in diameter of the exhaust pipe. For large engines a concrete pit outside the building may be used. An inlet

pipe comes from the engine, and the outlet pipe is led above the surrounding buildings so that the exhaust gases may cause no inconvenience. The size of the pit varies with the engine, but it is never much less than 3 ft. × 3 ft. × 3 ft. The attendants will be guided in the use of silencers and the care of exhaust pipes by the makers.

If an attendant, for any cause, has to extend either air, gas, or exhaust pipes, he should make very free use of union joints, as these assist at periods of cleaning. No pipe should be decreased in size from that provided by the engine makers. Provision for expansion of pipe lengths is generally made by slip pieces. A gas regulator is usually fitted with all engines. In small engines this takes the form of a rubber gas-bag, and in large engines of a gas-holder. On oil engines two fuel tanks are usually provided, or one tank with two compartments.

For maximum efficiency the air taken into the carburetter or mixing valve should be as clean and pure as possible so that compression can be carried to the highest point. Oil fuel requires that the air be heated almost to evaporation point of the oil. As the suction in the intake is comparatively weak the pipe should be at least one size larger than the pipe at the engine. When an inlet pipe is led to the open it is found that the valves work more quietly.

The foundation plan usually shows the position of the water-cooling tanks. These have already been discussed, but the attendant would do well to consider the position of pipes and drains. If the water is taken from a stream or well, a strainer should be installed in the pump suction pipe to free the water from sediment held in suspension. The pipes are usually of ample size and the supply regulated by valves, unless the pump is fitted with these. The makers provide for 10 to 15 gallons of water leaving the jacket at 130° F. per horse-power hour. The foundation for the circulating tanks should be such as to carry the bottom of the tank above the level of the bottom of the cylinder jacket. Above 50 horse-power the engines are fitted with a circulating pump worked by the engine shaft. There must be no leakage in the suction side of the pump. Inattention to this point will cause the pump to drop the water and stop the circulation. "Full open" and "shut" positions are marked on the inlet valves.

All pipes should be thoroughly cleaned before installation. Connections to the engine are made by unions, and pipe joints are so made that there can be no restriction in pipe area, either at the flange joint at the cylinder or at the other joints along the pipe lengths.

Approximate sizes for pipes are $\frac{1}{8}$ in. diameter for circulating

water and $\frac{3}{8}$ in. diameter for gas supply per square root of the horse-power of the engine.

It would be advisable to warn the attendants against the fault of leaving starting set screws in covers screwed against the joint faces. These should be well screwed back, so that when the heat comes on the flange there will be no chance of the flanges cracking.

After the engine has been completely put together and turned, either by pulling on the flywheel or barring the engine round or by small barring motor, it is ready for the gas or oil.

CHAPTER IX

STARTING, RUNNING, AND STOPPING THE ENGINE

STARTING and stopping are the two operations which follow on the complete installation of a gas or oil engine. It is here assumed that the gas supply is available, or that the fuel tanks are filled in the case of the oil engine, and that the valve settings have not been altered in erection. The engine will start if the following points are correct:

(1) Spark is right or ignition tube is hot enough, or plug in combustion chamber is hot enough for combustion.
(2) There is the right quantity of gas or oil.
(3) Mixture of gas, or oil vapour, and air is correct.
(4) Valves are not leaking.

The principle involved in starting gas or oil engines is much the same in each case. The attendant makes certain that the valves are not stuck, but are ready to open and close at the desired time. He sees that the water in the cooling tanks is above the level of the top water pipe, but not above the top waterway if there are two or more tanks, and also that the water cock on the bottom water pipe is open. Oil cups and lubricators are filled, even those which are already partly filled. Where grease cups are used on bearings he must make sure that they are filled with lubricant and screw them down to give sufficient pressure. The engines are set in motion in one of two ways, depending on the size of the engine. In small gas engines the igniter is set at the retard, and the half-compression cam is brought into use. Then, with the switch closed, the flywheel may be turned quickly in the direction in which the engine will run. One or, at most, two revolutions past the ignition point should serve to start the engine. When it has started, turn the gas valve to the running position and advance the ignition. In the case of the oil engine the lighted lamp has to be applied, so that the vaporiser may be sufficiently heated to start the engine. About six to ten minutes are required for this operation. The exhaust-valve lever requires to be drawn back to ease compression. Then, the driving belt being on the loose pulley or the clutch on the shaft disconnected, a small

quantity of oil is turned on at the oil valve (say a quarter turn) and the flywheel is pulled round quickly. At the commencement of the third revolution the governor drop-piece will swing up clear of the exhaust lever, and the engine will take in its first charge of air and fuel, which it will fire at the commencement of the fourth revolution. The compression cock, if open, must then be closed. The engine should gather speed and go on working without further trouble.

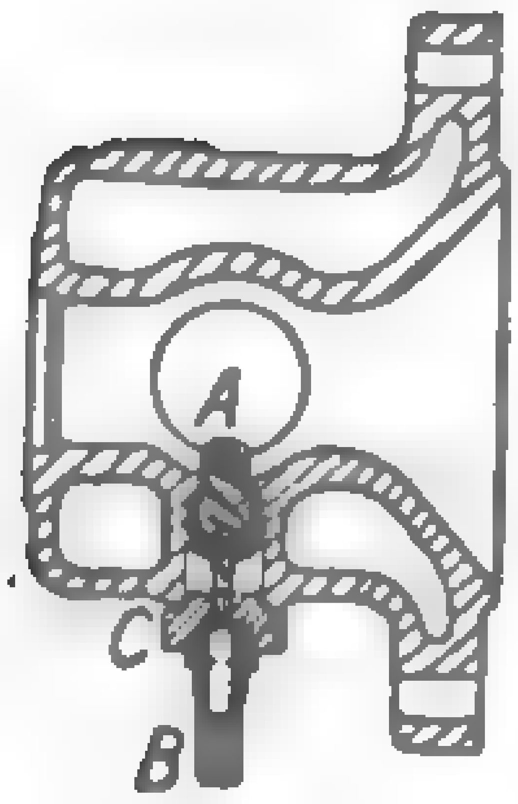

Fig. 63.
Hot-Spot Arrangement.

Very frequently in large gas engines compressed air of about 200 to 250 lb. per square inch pressure is utilised for starting up. A small compressor, forming part of the engine, may be used to charge bottles which act as a storage tank for starting up; these bottles are kept charged up ready for use. In very large plants a separate compressor driven by an electric motor is used to supply the starting air. Either of these two ways is very economical, but the first requires the attendant to be very watchful lest he should be left with empty air bottles and an engine at rest.

A barring gear working in a rack on the flywheel rim is frequently used. This is a substitute for pulling the engine round by hand, or barring with a podger bar to get the engine into the correct starting

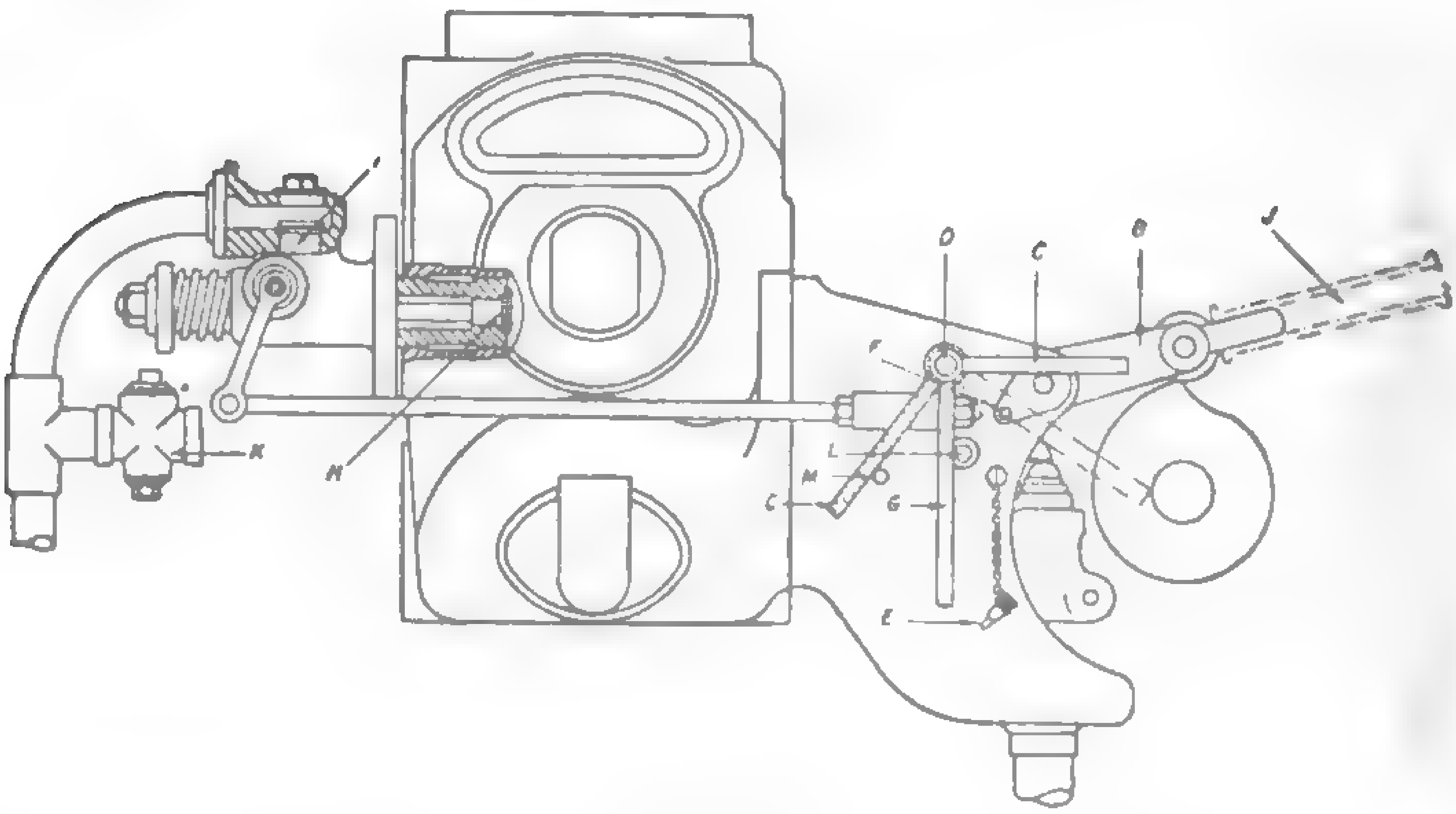

Fig. 64.
Fuel Pump.

position. An electric motor has its speed reduced through a set of gearing which acts as a lever on the flywheel rim; the operating and release gear is fitted with a mechanical device so that the motor will

not be caused to race after the engine has gathered speed from the explosions. Those attendants who have charge over large steam plants know that it requires a considerable time to start up a large steam engine or steam turbine. The gentle warming up, the cylinder or turbine draining, the gradual opening of the stop valve, and the cautious running of engine or turbine until properly heated up all take time. With the gas or oil engine the third or fourth revolution, when the air supply is closed, sees the explosions begin, and full speed may be attained in less than one minute from standing at rest.

Some oil engine makers recommend a compressed air pressure of 300 to 320 lb. per square inch and supply a hot-spot arrangement (Fig. 63), which receives heat from a blow-lamp and can in a very short time heat the plug which is placed in the combustion chamber. In working with this arrangement the object is to get the engine moving and then recharge the receiver, which may, by some chance in transit, have lost its pressure. The exhaust cam roller is always placed on the half-compression cam which was shown in Fig. 19. After a few explosions have taken place, and the engine has gained sufficient speed, the cam roller is moved into its correct working position on the exhaust cam. In starting up the engine the attendant should warn any persons helping him not to put their feet on the flywheel arms and always to take hold of the flywheel on the opposite side to that of the engine crank.

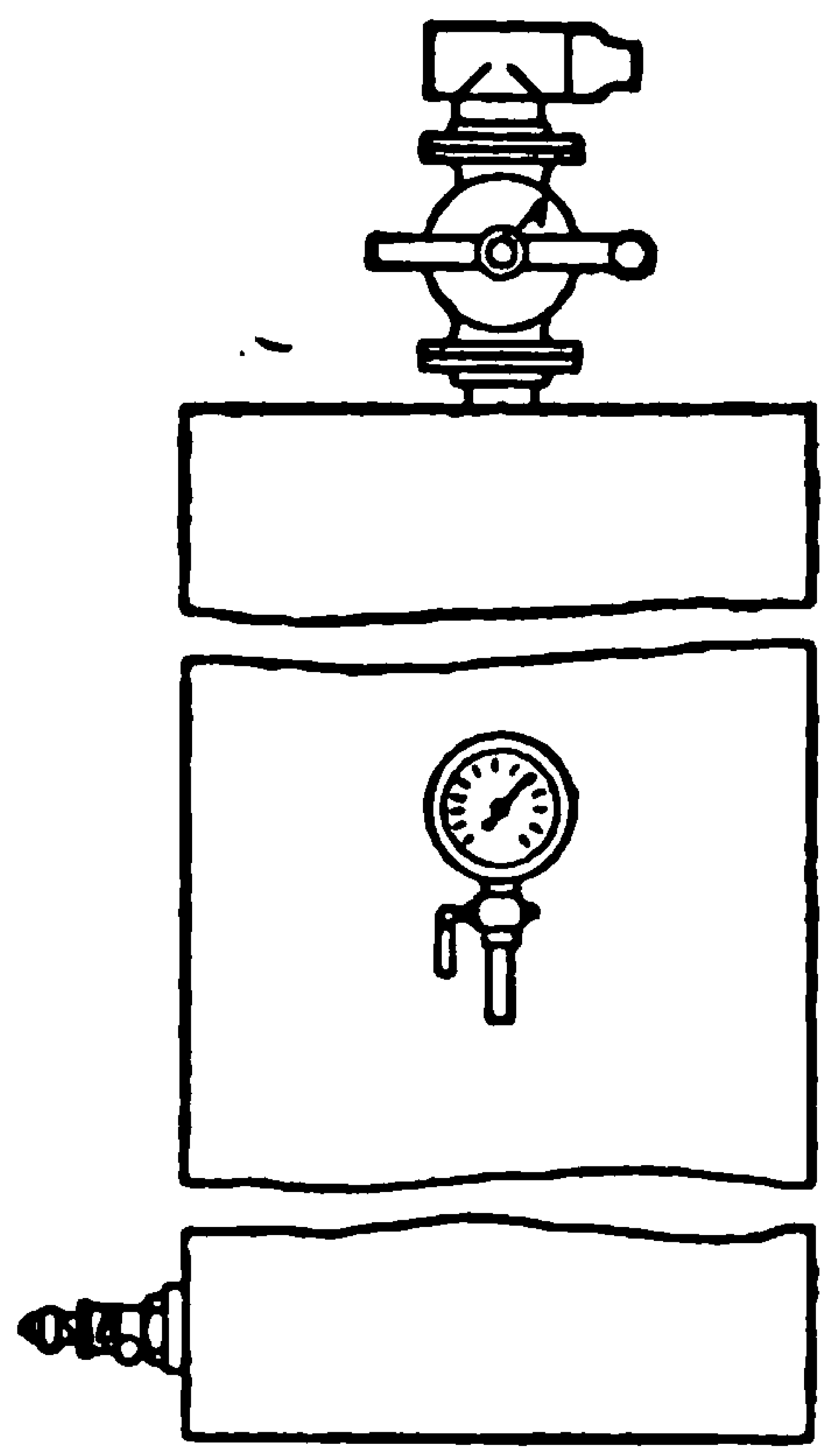

FIG. 65.
AIR RECEIVER AND STOP VALVE.

Charging the air receiver by means of the engine cylinder should always be done shortly after the engine has been started. In some instances it may be desirable to leave it over till just before the engine is stopped, but there is always the danger that the engine may be stopped before the receiver has been refilled. After the engine has been running for a few minutes and has become nicely warmed up, the fuel pump *A* (Fig. 64) is put out of action by raising the cam lever *B* and retaining it in this position by bringing the handle *C* of the sprag pin *D*, carried on the oil pump bracket, to the position shown in full lines. The stop pin *E* is inserted into the hole *F*; then the handle *G* is operated and retained against the stop pin *E*. The valve *H* only will then be open, and air will be forced from the engine cylinder through the

check valve *I* into the receiver. After the pumping has been continued until the engine speed is slowed down, the first handle *G* is released and also the cam lever *B* by pressing down *C* on the sprag pin *D*, when the fuel oil pump *A* will again come into operation. The minimum pressure in the receiver at which the engine can be started is 200 lb. per square inch. The stop valve *A* in the receiver (Fig. 65) must be tightly closed immediately after charging. An attendant must have an eye on the receiver gauge to see that no leakage is taking place and that minimum pressure is not reached. The above description applies to the Tangye engine, but all starting up sets are much the same in principle.

Engine Running

While the engine is running the attendant should see that all lubricators are acting; that rings are moving round with shafts; that the right quantity only of cylinder oil is being supplied; that the governor mechanism is acting freely; and that the number of explosions corresponds to the work given out by the engine. From the position of the governor, or from the number of explosions per minute, an attendant should be able to say "My engine is running at half-load," or three-quarters load, or whatever it may be. In running in a new engine it is advisable to stop the engine if any bearing should become overheated. A touch of blacklead and vaseline, or castor oil or sulphur, has been used with good effect on a bearing which was inclined to heat. The working of the gas valves should be watched and clearance on cams noted to see that all valves are returning properly to their seats. When working at full load the condition of the rubber gas bag or gasometer should be noted. In the case of the oil engine the oil connections must be examined to see that the oil is flowing freely between the oil tank and the sprayer. The cooling water supply must be regulated to keep the cylinder cool, yet not to a sufficient extent to reduce the efficiency of the engine. In the case of the gas engine, the cooling water gains approximately 40° to 45° F. in temperature and the oil engine about 60° to 70° F. A record of the amount of gas or oil used per hour should be kept as a guide to the amount of fuel required. It cannot be too strongly impressed on the mind of the attendant that any gas or oil taken into the cylinder beyond the quantity which the air in the cylinder will consume is wasted, since it is expelled to the exhaust unburned. The regulation of gas or oil will vary, then, with the quality of the fuel used, and should not be left to the governor.

Stopping the Engine

As far as possible the stopping of the engine should be carried out according to the directions of the makers. The following order of operations is common with small engines :—

(1) Shut off the gas valve at the engine.
(2) At the meter, close the gas cock which leads to the rubber gas bag.
(3) Close the gas cock to the ignition tube or disconnect the magneto.
(4) After the engine has cooled down sufficiently, shut off the circulating cooling water.
(5) Turn the engine with the crank at the bottom centre of the compression stroke ; in this position all valves will be closed.

In the case of the small oil engine the oil valve on the vaporiser is shut ; the oil is turned off at the valve on the oil cistern, and then the valve supplying the lamp with oil is closed. If the valve is of the pump type, the air-escape cock should be opened. As the engine is stopping the compression cock is opened in order to clear the cylinder. When the engine is at rest it is advisable to turn the flywheel until the piston is inside the cylinder and so protected from dust, while the exhaust valve is closed so that the springs are not extended. All syphons and lubricators should be stopped from supplying oil to the bearings. When heavy oil is used it is advisable to use a small supply of petrol to burn off any gumming material which may have formed. This last operation is carried out by placing the pointer on the oil fuel supply tank at " refined."

Some makers give the following instructions, which are practically the same as those set out above :—

(1) Cut out the action of the fuel pump plunger by means of the hand lever, when the engine will immediately slow down and stop. Keep the fuel pump lever depressed by means of the stop provided.

(2) Close the cock on the fuel supply pipe.

(3) Open the compression cocks ; turn the engine round to the starting position ; close the compression cock. (Do not shut down the engine completely if the vaporiser is red hot, but allow the engine to run light.)

On all engines the working positions are clearly marked by means of plates, and the working is easily learned. Remember to keep the starting air bottles or air receiver fully charged and to put the belt on the loose pulley or disengage the clutch, so that the engine will be ready to start up on light load.

To guide the engine attendant it is advisable to have a recording calorimeter, which will give the B.T.U.'s in the gas used at least every half-hour. A recording barometer should also be provided. An engine-room log, as used aboard ship, should be kept both for the satisfaction of owner and employee. Indicator cards should be taken from the different engines or cylinders of multi-cylinder engines. The use of these will be explained in a later chapter.

CHAPTER X

STARTING, RUNNING, AND STOPPING THE GAS PRODUCER

INSTRUCTIONS suitable for all classes of producers cannot be given here, but for the ordinary suction gas producer plant, working in conjunction with a gas engine, the following can be applied.

When starting from cold it is necessary to try the blow-off and test cocks, and any water which may be left in the producer should be drained off. The water supply in the scrubber can be turned on ready for use, and the evaporator may be filled. Both water and steam valves are closed. A fire may now be kindled. Some wood is placed on the top of a piece of waste which has been dipped in paraffin. This will give the fire a start. A few pieces of wood are then dropped in from the hopper, followed by some coke in small pieces. The hopper valve should be examined to make sure that it is clean and capable of making a good joint with its seat. This valve can now be closed. At the same time the cock or damper in the chimney pipe must be opened so as to cause a natural draught. Water is admitted to the vaporiser and ashpit of the generator by opening the water valve. This should be done before the fire has got much of a hold. Then, and not till then, the fan should be applied. After a few minutes it is advisable to stop the fan and to open the fire door to make sure that the wood is alight. This should be done quickly.

As soon as the fire is well alight the hopper may be opened and the generator filled right up to the top. The fan should then be turned steadily and slowly, about sixty times per minute, until the gas escaping from the test cock on the chimney pipe can be lighted. The next operation is to open the cock on the expansion box near the engine, thus allowing any air to be driven out, after which the escape cock on the chimney pipe is closed. One or other of these cocks should be opened when using the fan before the engine is started. A plentiful supply of water is turned on in the scrubber, and then the attendant makes certain that the engine is at rest in a position such that all valves are closed. Neglect of this precaution would allow gas to fill the engine room.

By applying a light to the small test cock just below the engine inlet valve the gas may be tested for quality near the engine. When this jet burns well the engine may be started up and the gas test cock closed. As soon as the engine is running at full speed the cock from the expansion box should be closed, and at the same time the air valve to the generator should be opened, after which the fan may be stopped and the air inlet to the fan closed. The level of the fuel in the generator should be kept fairly constant, and, in charging, care must be taken to see that the level of the fuel is above the container. The cover valve on the hopper should always be closed before the lift valve is opened, and the attendant should see that this lift valve is sitting perfectly on its seating after each charge. This is done by moving the lifting lever once or twice to shake away any small pieces of the charge which may lodge on the seating.

As has already been stated, a good and steady supply of gas requires a selected fuel. The attendant, however, can do much to make the plant a success by careful attention. Clinker will form and must be cleared away. The generator will burn down and require recharging at regular intervals. A proper supply of water for producing the necessary steam in the vaporiser is required, and must be regulated so that the rate of water consumption is about 1½ gallons per hour for each 20 horse-power developed at the engine shaft.

In shutting down the plant the gas cock on the engine is shut, and as quickly as possible the escape cock on the chimney pipe must be opened, and also the air valve between the generator and the fan. If the stoppage is only for a short period, the cock on the chimney should be regulated, and the air valve leading to the generator opened, so as to maintain a sufficient supply of air to keep the fuel smoldering and to have the producer in good order for starting up quickly. The attendant will soon learn to regulate these valves to suit the period of stoppage, since they give a nice adjustment to the amount of fuel used. The water flowing into the vaporiser should not be shut off completely, or then overheating, followed by damage to parts, will result. The supply could be checked down to about a fourth of the working condition supply; on starting up again, make sure that the full supply of water is running. If the producer has been standing overnight, the clinker must be got rid of by working the slice bar across the grate. Also the charge should be poked down from the stop, as it will have burned hollow. Rake out the clinker, and make sure that after clearing the ashpit the doors are closed and the joints perfectly airtight. Fill up the container, opening all damper cocks, and start the fan so that the gas will be freely flowing, before attempting to start the engine. All clinker and dirt should be cleared away from

the plant. The fire in the generator should be drawn once per week, and a careful attendant will not waste much fuel in doing this. He also knows that the more carefully he cleans out the better will be the results of his gas making during the following week. To work a producer day and night for six days requires careful and quicker clearing away of clinker, and that the valves should be kept airtight. Experience is the best instructor which can be had, and it will be found that to keep a gas engine going night and day is no more difficult than to keep a steam engine and boiler going for the same period without stopping. Cleaning every eight hours is quite usual with good fuel, but with indifferent fuel, which forms clinker very quickly, the time of cleaning is left to the attendant. Choking of the drain pipe while cleaning must be guarded against, and this pipe must be kept quite free of obstruction.

During a week-end cleaning the clinker should be removed from the brickwork, and the space between the firebars can then be thoroughly cleaned. It is advisable to damp down the producer for some time before drawing the charge completely.

The coke scrubbers require little attention, but the attendant should be careful to keep the inside of the scrubber painted to avoid rust. The layers of coke should be selected. The bottom layer requires changing more frequently than the top layer—usually every six months, as against a period of twelve months for the top layers. The two layers of shavings, with intermediate layer of sawdust, require changing along with the top coke. A plentiful supply of water must always be used and the base of the scrubber cleaned out every two weeks.

CHAPTER XI

CARE OF THE ENGINE

An attendant who has little or no experience with plant and engines is apt to think that because he has given the engine gas, lubricating oil, and water he has done his duty, and that the machinery requires no further attention. A good attendant, on the other hand, can tell by the sound of the engine in motion, by the position of the governor balls, if the engine is working well and the plant giving the best results. The engine and plant will sometimes work well under adverse conditions for a long period of time, but to get the full power, and to keep the engine going in service for the longest time, the right kind of fuel, lubricating oil, skill in manipulation, and a watchful eye are necessary. It is found essential in most cases to filter all oil fuel before using and to pay particular attention to the washing and purifying of the gas from the producer. Grit or solid matter, either in fuel oil or gas, will interfere with the lubrication of the cylinder.

It is recognised on all hands that engine and plant stop nine times out of ten for want of small attentions which have been neglected. The engine makers are responsible for: (1) the design and suitability of the engine; (2) the material and manufacture; (3) the workmanship and erection. But the engine users and attendants are responsible for: (1) supplying these engines with clean and cool gas or oil; (2) with clean, cool, and soft water; (3) regular lubrication with oil of proper quality and in proper quantity; (4) systematic cleaning of gas pipes and water jackets; (5) inspection and cleaning of cylinders and valves to remove dirt, carbon, and other deposits; (6) proper maintenance of spare parts, ignition plugs, spare exhaust valves, piston rings, etc.; (7) (in large engines) piston packing, taking up of brasses, preventing knocking, and, in particular, maintaining true alignment of piston and shafting by paying attention to the possibility of the settling of foundations.

It must always be remembered that the engine works, not with gas only, but with gas and air or oil and air. It is important that the two should be in proper relation one with the other. The exhaust valve, air valve, and gas valve should be taken out periodically, cleaned, and

rubbed into their seatings. In the case of the oil engine, the vaporiser valve, if one is used, requires the same attention. A black-lead pencil mark at four places on the face of the valve will, when rubbed on the seating, give a correct indication of the bearing of the valve. If the engine is to work night and day, this must be attended to once each week. Should the valve faces or seats show pitting marks they must be ground out. The usual method is to put a little lubricating oil on the face of the valve and on this sprinkle some flour emery or ground glass, followed by fine emery. The valve is now placed carefully on its seat and the faces rubbed together. Sometimes a tool is provided for this grinding operation, and at other times there is a screwdriver notch on the valve head into which a tool worked by a hand brace is placed. A few applications will suffice unless the valve face is very bad. After grinding, carefully clean away all gritty oil and emery.

The exhaust valve needs most care, as this valve is working under most adverse conditions and at very high temperatures. If the valve is not properly seated, gases at high temperatures (Fig. 69) pass through a narrow slit and frequently cause damage to the face, and may even cause fusion of the valve face to the valve seat. The only remedy is to turn the valve face and possibly machine the seat. This changes the valve timing. It is this damage which must be guarded against, and the attendant cannot take too much care to see that exhaust valves are well bedded on their seats. Again, the motion of the rocker lever is not such as to give a vertical lift to the valve. In fact there is a tendency for the valve spindle to be thrown out of its vertical movement, especially when the spherical end of the valve spindle has become worn. The point of contact between lever and spindle requires frequent inspection for deformation of contact point due to wear. A valve ought to be made to turn round in its upward movement. Often it is found that the case-hardened screw point has worn a hollow in the valve stem. The side pressure on the spindle causes a flat to wear on the spindle. This may cause the valve to be held up from its seat. A worn valve spindle guide should be bushed at once, or the valve seat will wear round and require to be renewed.

On the pin of the cam roller which lifts the exhaust valve there is a considerable pressure, as the pressure on the exhaust valve is between 40 and 50 lb. per square inch. This means that the roller pin must be well lubricated to avoid seizure or wear, which in turn forms flats on the roller. The exhaust cam is usually wider than the inlet valve cam. The clearance between the cams and the levers when the valves are shut must be maintained, but in the case of the exhaust valve

cam this clearance must not be excessive, owing to the acceleration force set up on the moving parts. No heavy pounding of roller, or cam against roller, should take place.

The end roller faces must be oiled, and even then, after a time, the nose may get worn off the cam. It is cheaper to fit a new cam on the shaft than to attempt to dovetail a piece on to the cam. It is better to have a sliding exhaust cam roller than to have a cam sliding on a feather fixed in the cam shaft. In the sliding cam the feather becomes chewed, owing to the force being transmitted through an easy-fitting key. Should a new cam be required, care must be taken to have a key seat cut in the correct position relative to the cam profile.

The valves of an engine are usually very carefully set on the test bed of the engine shop, but when they are placed in position on the site small changes often require to be made. As in the case of the exhaust cam, so also with air and gas valves, a clearance is necessary between stem and roller when the valve is hard down on its seat. These clearances should be retained, and valve spindles must pass freely through their guides. Any part of a valve spindle which is pressing too hard on the guide becomes very much brightened up. This part should be eased off with a smooth file and rubbed over with emery paper.

The adjustment for lift of valves is usually made by means of a regulating set screw with locking nut (see Fig. 16). The lever will be able to rock slightly when the roller is off the cam and the valve is resting on its seat. Very little, if any, attention is required for these adjusting screws, but it would be advisable to see that the jamb nut is locked carefully should the screw require adjusting. The exhaust valve springs are designed to be strong enough to pull the valve tightly on to the valve seat and to hold it there. On some engines these springs are adjustable, but other springs have been calculated to give just the required tension. The use of correct springs, and the correct spring tension or compression, is very important. It is usual to make the spring exert a pressure of 1 lb. per square inch of valve area, but this must be increased up to 12 lb. in the case of quantity governing, or the valves may lift. Compression springs are nearly always used. A spring is such a simple device that it is very seldom looked at by the attendant. Yet care of the springs may save a lot of trouble. Weak springs cause a noisy working engine; therefore they should be given consideration. A permanent set is given to a spring by constant use. When the springs are too strong they cause unnecessary wear on the valves and are themselves worked out sooner. The putting in of a washer to give strength to the spring

should be considered as a makeshift, and a new spring ordered from the makers.

Any wear that occurs in the valve-operation gear of an engine affects the valve setting, causing loss of engine power. When the correct settings have been obtained, the crank angle at which the igniter snaps in the running position and the time of opening and closing of each valve should be noted by marking the flywheel rim—a chisel mark with the letter "I" typed above it, such that when this mark is levelled up by spirit level the igniter is just on clicking point. Another line marked "O" and a third marked "C" would be shown. Sometimes the maker of the engine puts on these approximate indications. The marks are only to act as guides when setting the valves after repairs or cleaning, but will not hold when a different quality of gas or oil fuel is used.

An engine working on town gas and running at 240 revolutions per minute makes four revolutions per second, and therefore passes through (4×360) degrees of crank angle (*i.e.*, 1440 degrees) in that period. The igniter must be set for 36 degrees of crank angle to give $36 \div 1440 = 0{\cdot}025$ second duration for the complete lighting of the material charge. For producer gas the ignition point must be set at 72 degrees crank angle before the in-dead centre; this will give 0·05 second for completion of ignition. A study of these examples will assist the attendant to understand the effect of retarding or advancing the spark.

If the points as marked on the flywheel or as given by the above calculations are kept in view, the alterations to allow for wear may be made more easily. Just when the valves lift or close can be found by means of a piece of paper or a feeler placed between the roller and the push rod or cam lever. When the paper or feeler is gripped, the line on the flywheel should be marked, and the point at which, after the engine is turned in the direction of motion, the paper or feeler is released is the point of closing, and is marked on the flywheel as previously described. The checking of the valve setting now becomes easy, and ought to be carried out after re-grinding the valves. Always take the engine up to the marks, so as to keep any slack from affecting the valve settings.

It is of the utmost importance to use the right class of lubricating oil, and, as stated before when dealing with bearings, the engine makers are ready and willing at all times to give first-hand advice. With all high-speed engines, medium body mineral oils give the best results for gas and oil engine cylinders. Never be tempted to use the heavy class oil used for steam engines, and do not use animal fat oils. A good oil for use in gas and oil engine cylinders is refined and

almost wholly free of carbon, and is not very thick. Heavy duty engines require an oil which is much heavier than that used in high-speed, light engines. The chief objection to heavy oils is that they offer a higher resistance to the motion of the moving parts, and some of these oils leave a bad carbon deposit. On the other hand, if the oil is too light it is liable to burn up ("fry" is the term used), leaving carbon behind. When a suitable oil is found which suits the best average working conditions, it should always and at all times be used. A change of cylinder lubricating oil often leads to much trouble and is not economical. The attendant must remember that the higher the temperature of the cylinder walls or the cooling water temperature rise, and the heavier the load the engine has to carry, the heavier the lubricating oil must be, and *vice versâ*. Never buy an oil because it is cheap, or you may find the piston rings sticking and not able to perform their function; the valves may be hard to open for the same reason. Smoke from the silencer and exhaust will be troublesome, and this smoke should be immediately taken as a serious warning. If in doubt about an oil, write to the engine makers and have an oil which will retain its full lubricating properties at 650° F. without any carbonisation whatever taking place. Such oils are Messrs. Dick's B.M.E. cylinder and Messrs. Dick's B.M.E. engine oil, or the National gas engine oils for same.

Almost any class of good machine oil will suit for engine bearings, but it is advisable that this should not dissolve too much fuel oil.

It would be well to have regular periods for cleaning the piston and cylinder; this must be done at least once in twelve weeks. When the piston is out it is not always advisable to remove the rings from it. The rings should be moved about while washing with paraffin until quite free. It is well known that a small deposit of carbon helps to keep the rings tight. Carbon allowed to grow below the rings will cause too much pressure on the cylinder and will wear ridges in the liner. Piston rings ought not to be allowed to run after sharp edges are formed; these edges should be chamfered off on both sides, since when sharp they act as scrapers on the cylinder and run very dry. See that the pins for locating the piston ring positions are in place and not projecting above the surface of the piston. The horizontal engine has the piston rings with openings on the bottom half of the piston, and staggered. In the case of vertical engines the ring joints are placed at the sides—never at the front or back—of the piston, there being no sway sideways.

All carbon and dirt deposit should be scraped from the back of the piston and from the hole in the top of same. Also, the recess which conveys the oil must be thoroughly cleaned. In replacing the

piston be sure that the correct side of the piston is looking to the front or is to the top. (Always note the method of lubrication.) The exhaust passages in the cylinder must be cleared and cleaned of soot. Clogging of the exhaust passages will cause back pressure and loss of power. These passages, however, get attention when cleaning the valves and should not give trouble. Remember that on the cleanliness of the gas or oil fuel will depend the length of time between the cleaning periods. It is rather unfortunate that in some makes of engines so much has to be done before cleaning can be carried out thoroughly. In a well-designed engine an hour would suffice, but with other engines this time is greatly exceeded, owing to the number of small parts which must be removed. Inspection plugs are usually placed in such positions that they may be utilised for cleaning purposes.

Considerable space in this book has already been devoted to cooling water systems, but as the water jacket and cooling system usually receive scant attention it is thought best to warn the engine attendant here. Inattention to this part of the engine may easily cause a long stoppage. Many waters used carry much lime in solution; also sediment comes through any filtering system, and the deposition of these will clog the water jacket. Where the water is hard a softener is used. A handful of soda put into the circulating tanks once a month may clear the water before it reaches the cylinder. With all waters a deposit collects gradually at the bottom of the jacket and in any pockets in the jacket system. This is sure to cause local heating, which, if allowed to continue, will crack the cylinder. Circulating pumps require special attention. They must not work under their proper speed. Belt-driven pumps may cause stoppage on account of the belt slipping or breaking; the belt, if one is used, ought to be examined every day.

Determination of the value of the water jacket temperature for best results is largely a matter of experience, but the following points will act as a guide:—

(*a*) Other things being equal, the higher the jacket water temperature the higher should be the thermal efficiency of the engine, on account of the better combustion and the decrease in loss of heat in the jacket. Against this, a greater amount of heat is carried away by the exhaust, and friction is increased, due to difficulty with lubrication.

(*b*) With some fuels pre-ignition, or ignition before the proper time, due to hot jacket water, gives trouble on account of insufficient cooling during compression. As against this, when the cylinder is too cold, condensation of oil may take place.

(*c*) The power capacity of the engine can generally be increased slightly as the temperature of the cooling water increases, but great increase in temperature may be found to have the opposite effect, due to the heating of the charge during the suction stroke, which decreases the weight of the charge by causing it to expand.

(*d*) Small engines can generally be worked with higher jacket water temperatures than large engines. The weight of cooling water can be more easily dealt with, and a larger proportion of cooling surface per inch of cylinder content makes cooling more effective. In large engines the castings are more complicated and more liable to overstrains. It is therefore more desirable to maintain an even cooling in the larger castings.

If by any mistake the cooling water has not been turned on to the jacket, and the engine begins to smoke through the open end of the cylinder, care should be taken not to send the cooling water suddenly into the jacket, or cracking of the cylinder may take place, or the piston may seize in the cylinder. It is better to flush the cylinder with a plentiful supply of oil and to send the water into the jacket as slowly as possible, gradually increasing the supply.

Keep careful watch on the igniter. This is by far the most important operating detail in the whole engine. Valve seatings may be good or bad, cooling water at a high or low temperature, compression pressure perfect or otherwise ; but in the case of ignition differences in power are at once noticed if the ignition is faulty, due either to mechanical defects in the igniter or to an incorrectly proportioned explosive mixture, which may be more or less capable of being ignited. All parts of the Bunsen must be properly cleaned to give a good Bunsen flame and a bright, cherry-red ignition tube. The thumbscrew at the top of the chimney should only be tightened down by the fingers ; no spanner or tool should be used. The points on the igniter require cleaning almost every week; not more than four weeks can be safely exceeded, or the engine may stop without warning. If a bad quality of coal, producing dirty gas, is being used, the ignition plug may require cleaning each morning before starting up. In cold weather moisture gathers on the plug, and heating is sometimes resorted to prior to trying the engine. The actuating mechanism must be kept in such good condition as to release the trigger from the catchpoints so as to give a free, easy, and decisive movement to the striking spindle or lever. There should be no excessive slackness, nor yet undue tightness, in the fit of any striking rod and its guides. The striking plate fitted on the sparking plug has a clearance of $\frac{1}{64}$ in. (nearly), and this clearance is adjusted from time to time by the adjusting screw or compensating device.

In cleaning the plugs the following observations should be of value :—

(*a*) In each plug, as previously illustrated, there are two spindles, one fixed, while the other is the oscillating spindle. Leakage at the fixed spindle is avoided by the use of asbestos washers, which seldom require renewal, but a flat is worn on the working face and requires to be turned or filed away.

(*b*) The moving spindle, on the least sign of sticking, should be taken out and cleaned with paraffin, and the hole in which it works should also be cleaned with paraffin. Be careful not to destroy the spindle-screw thread when knocking it out. Use hard wood, or screw the nut to the end of the spindle to protect the thread. When the seatings of the spindle show signs of corrosion or pitting a little fine emery and oil should be used to grind them together. As in the case of the instructions given on the care of valves, all traces of grit or emery must be removed before returning the spindle to its place.

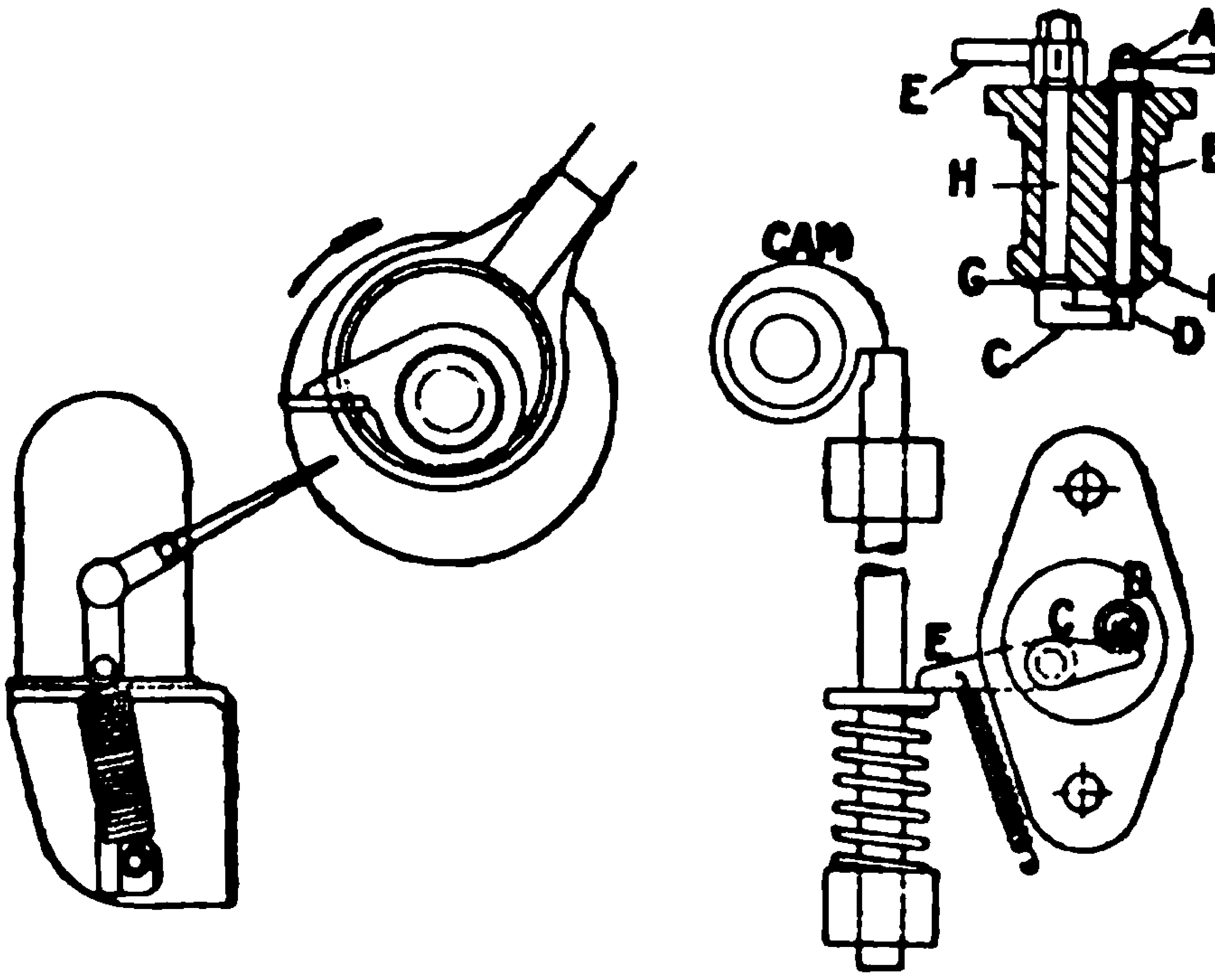

FIG. 66.
"MAKE-AND-BREAK" IGNITER.

(*c*) It is of vital importance that the tappet lever on the end of the movable spindle be put back in its proper position.

(*d*) When the small spring is put on, the complete plug is ready to be fixed in the engine cylinder. Excessive strain must not be put on the nuts which fasten the plug to the cylinder, and care must be exercised in dividing the pressure equally among the nuts so as not to tilt the flanges.

(*e*) Examine the connecting wire to see that a proper connection is made with the brass terminal screw.

A sketch of "Make-and-break" igniters is inserted here (Fig. 66) so that the above instructions may be followed.

The magneto itself is a part which seldom fails. Keep it free from oil and do not allow it to get dirty. The strong spring which causes the trigger to fly back into position is fitted with a steel roller at each end, and these should be lubricated occasionally. Oil the

magneto bearings regularly, but do not flood them with oil. At the end of the magneto is a milled brass cap screwed on to the armature bearing. This may be taken off occasionally to see that the contact is free from oil, rust, or dirt. In case of emergency it is often considered a good plan to have a battery charged and ready for use should the magneto fail, but this is becoming less and less essential, as magnetos are well made and work with unceasing regularity with but little care. But it cannot be too strongly impressed on the mind of the attendant that the magneto is the life and soul of an engine, and on good ignition depends whether the engine will painfully crawl round under full load or romp on as if it had a great excess of power.

If hot bulb ignition be fitted to an oil engine, the bulb may have to be taken off and scraped now and then, or possibly renewed. It will probably be found that the heat has set the nuts hard. If so, they should be soaked in paraffin and given a few hours to allow the paraffin to get well into the screw threads. Usually this has the effect of loosening the nuts, which can then be readily taken off.

The lubrication of the engine is generally considered of the utmost importance, and attention to this will do much towards smooth and quiet working and increasing the life of the engine. Feel the bearings occasionally and keep a close watch on the oil cups and sight-feed lubricators. Sometimes it is advisable to keep an oil record card. This assists as an indicator regarding supply and prevents waste. The cylinder, or rather the piston, must receive its one drop per inch of cylinder diameter of fresh oil per minute, but all the other parts of the engine can be supplied with filtered oil. Filtered oil may be used over again when cooled down; it is found that its lubricating properties are not impaired through use. In the case of a hot bearing, do not cool down too suddenly. Loosen the bearing, and remember that by cooling the shaft the bearing becomes free, due to the shaft contracting away from the surrounding bearing. Keep the wicks in syphon lubricators clean by washing them occasionally in paraffin. The brass holders carrying the wiper on the crank pin should be regularly taken off and cleaned every three months. It is advisable that all oil passages be kept free.

The bearings will only need taking up now and again. Pay special attention to alignment if any bearing is liable to wear more than another. Very thin steel plates are usually provided for taking up wear. Be sure to remove the same thickness from both sides and to draw down the cover evenly; the bolts should be tight, but the covers or brasses must not be bent. Never run the engine on the working load with bearing bolts slack. The tightness of connecting rod bolts must be tested occasionally. Taking up main bearings and

connecting rod bearings is not a job for the average attendant, and it must be left to the experienced fitter or mechanic, but the attendant must never hesitate to report on the condition of bearings, as the tendency of all slack or worn bearings is to become worse if neglected.

Be sure to replace all locking arrangements, either jamb nuts, lock washer or cotter pins, as the case may be, before starting the engine, if any should have been loosened.

Keep the governor working freely and carefully adjusted. See that the gas valve opens promptly in the case of hit-and-miss governing, and that the miss has not taken place due to sluggish action of the governor. Good governing means economical working and safety.

In order to operate two or more engines, or a multiple-cylinder engine, with maximum economy, it is necessary to load each engine as equally as possible, or to have each cylinder performing an equal share of the work taken out at the crankshaft.

CHAPTER XII

ENGINE TROUBLES AND REMEDIES

Much has been written about the troubles which arise in the working of gas and oil engines, and many explanations of how to deal with these troubles have been given. The following faults may occur when the engine is out of adjustment, and the directions given here indicate possible remedies. Engine defects may be either of a mechanical nature common to all engines, or they may be peculiar to gas and oil engines.

A. **Engine will not Turn.**—This is not a difficult fault to locate. It may be accounted for as follows :—

(1) A seized bearing.
(2) Overheated cylinder gripping piston.
(3) Friction clutch not clear or bolts rubbing on base or guard.
(4) Broken gears becoming wedged.
(5) Water in cylinder due to leaking water jacket.
(6) Obstacle (such as a spanner) blocking gear wheels.
(7) Broken countershaft.
(8) Dry bearing or rusted piston.

If caused by a heated bearing, loosen the cap and increase the lubrication. Where the bearing has seized tightly the brasses will require to be scraped and cleared of grit or abrasive. The pins and bearings may require to be smoothed up. Never use emery cloth to smooth down white-metal, for particles of emery sink into the soft material and cause trouble. A bent or sprung crankshaft may have caused the heating, and this must be attended to after the bearing has been cleaned and scraped. This is not easy to rectify, and the shaft may require to be put in the lathe after straightening.

A piston may become tight in two ways. The cylinder may overheat, or the piston may go dry, the excessive friction causing seizure. The first of these may be caused by a closed valve or water supply pipe or by retarded ignition after the engine has been put on full load. The remedy is to increase the water supply and the lubrication. Overloading the engine will cause overheating. This fault is indicated by the governor remaining open, while the engine has no misses, an explosion occurring on every explosion stroke. Smoke and smell of

burning oil will attract the attention of the attendant. If the heating has become bad, the engine must be stopped. When a piston runs in a dry condition it becomes scored and wears rapidly.

If the engine has been standing for any length of time, the jacket water has a tendency to leak. This leakage will cause rusting-up of the piston. Sometimes a spongy casting for the piston block has been known to show up sandholes and to leave grit in the cylinder, ultimately causing piston seizure.

The other defects which may render it impossible to turn the engine can be easily observed by a careful attendant. He may not be able to rectify a broken gear wheel, but he can at once report, and pin teeth may then be put into the gear while a new wheel is on order.

B. **Starting Troubles.**—In connection with new engines, the faults which used to give much trouble in starting up are gradually becoming fewer; the design of engines is much improved, and the starting gear is becoming, mechanically, more efficient and easy to work. The small imperfections, breakages, or neglects which may lead to defective starting are :—

(1) Fuel valve closed at oil tanks or gas shut off at meter.
(2) Battery or magneto switch open ; a broken, disconnected, or short-circuited wire ; weak battery or magneto not generating.
(3) Dirty electrodes on "make-and-break" ignition ; sooty sparking plug in high-tension systems.
(4) Defective spark coil in high-tension system or defective timer.
(5) No compression, indicated by engine turning easily over centre.
(6) High altitude and air leakage.

These are a few of many small troubles which disappear by experience and attention on the part of the attendant. The barring of the engine may cause the switch to open. Disconnected wires causing bad contact may be due to engine vibration. The dirt which may lodge on the electrodes can be shaken off by working the movable electrode several times ; failing this, the plug must be removed for cleaning. It should then be tested before returning it to the cylinder. Should it be found that the fault lies in a broken spring on the electrode, a new spring is the only real cure, but a temporary repair may be effected with rubber bands. Short circuits may be caused by placing steel tools on the connections, or they may be due to moisture. When working with a battery it is well to remember that one cell may cause the battery to be weak ; when this one is replaced the others may be found quite good. In larger stations there is always a testing voltmeter, as batteries deteriorate rapidly and must be tested from time to time.

The magneto may fail to generate because of a slipping friction pulley, a loose belt, or gear slipping on shaft. Not only must a magneto be properly driven ; it must be correctly timed. Bad contact is often made through oil or moisture on contacts ; loose pins and flat rollers cause an open circuit. In connection with high-tension magnetos, when the coil is in good condition a solid blue-white spark is produced ; with a faulty coil the spark is broken up or scattered like a spray instead of a strong solid spark.

As the atmosphere pressure is less at high altitudes, the density of the air is lower, and hence it is evident that all air should be increased in order to admit the same amount of oxygen at an increased volume. The makers of engines provide larger air valves and bigger nozzles to encourage the flow of the fuel.

C. **No Power or Loss of Power.**—There are many causes for gas and oil engines failing to give their rated power, but these usually fall under a few general headings when the small, or petty, causes are neglected. The more usual causes are :—

(1) Fuel valves are jambed, giving too small an opening or no opening at all.
(2) Air damper closed in intake pipe.
(3) Compression relief cam left in starting-up position. It should be put in working position as soon as the engine has started.
(4) Throttle left by chance in starting position.
(5) Weak batteries or vibrator adjustments giving poor spark will cause loss of power.

These faults are easily rectified, but the chief causes of loss of power are :—

(*a*) Leakage ;
(*b*) Improper valve and ignition timing ;
(*c*) Overheating of piston and cylinder or main bearings.

Under (*a*) will come piston ring leakage, valve leakage, and, in double-acting engines, packing gland or cage leakage. Usually leakage of any kind comes on gradually and causes a falling off of power developed. The engine gets harder to start each time. An indicator card taken from the engine, or each cylinder of the engine, will help to locate the trouble. A stuffing box leak is readily seen, but piston ring and valve leakage is more difficult to detect. Exhaust valve leakage is a very common and persistent cause of power loss. Test for compression by turning the engine over dead centre on the compression stroke. If it passes over easily, leakage exists and must be stopped in order to prevent power loss and waste of fuel. The exhaust pipe from a leaky valve becomes abnormally hot. The remedy is to re-grind or re-seat the valve.

Piston ring leakage on a single-acting engine may be detected by blowing through of gases. In a tandem double-acting engine, firing by pre-ignition in one cylinder may be caused by the hot leaking gases igniting the charge. If the engine can be stopped for some time, block the flywheel with the engine in the firing position and turn on the starting air. If the starting air whistles out into the crank case in the single-acting engine, or out of the opposite side of the piston in a double-acting engine, the trouble is a leaking piston, and if the air rushes out of the exhaust pipe it shows that the engine has a leaking exhaust valve.

Inlet valve leakage does not often occur; backfiring is the usual warning. Excessive warming up of the inlet pipe also denotes leakage.

New piston rings should be fitted one at a time. The ends should not be closer than $\frac{1}{64}$ in. when the ring is pushed into the cylinder free of the piston block. If the ends of the ring are closer than this the ring will probably break when expansion occurs. The best way to get the rings off and on the piston is by means of two or three long strips of thin steel. Do not allow the rings to snap into place.

Referring to (*b*), valve timing or setting: this subject has already been dealt with, but as it is very important in the efficient working of the engine, it will be advisable here to record points which would tend to change the setting or timing. The exact time at which the valves of a four-stroke engine open and close depends to a great extent upon the speed of the engine, the fuel used, the compression pressure, and the relation of the bore to the stroke. The principal factor, however, is the engine speed, as attention must be paid to the amount of time required to get the charge into and out of the cylinder. If the inlet valve opens too late or too slowly, the charge will not fill the cylinder without expansion; if the inlet opens too early, the hot gases in the cylinder will ignite the combustible gas in the carburetter and cause backfiring. Incorrect timing may be due to incorrect mesh of gears after dissembling, or, in the case of the ignition in a multi-cylinder engine, the wires may be attached to the wrong terminals.

An overheated cylinder or excessive back pressure is usually the result of the exhaust valve opening too late. Too early opening of the exhaust will reduce the pressure on the piston in an effective part of the stroke and will reduce the power of the engine and overheat the valves. Probable setting is as follows, but much depends on speed:—

(1) Inlet valve starts to open when crank is 20 degrees from head-end dead centre (approaching).

(2) Gas valve starts to open when crank is 10 degrees from head-end dead centre (approaching).
(3) Exhaust valve closes when crank is 15 degrees from head-end dead centre (leaving).
(4) Maximum lift of inlet gas valve occurs when crank has moved through 95 degrees from head-end dead centre.
(5) Gas valve closes when crank has moved through 200 degrees from head-end dead centre.
(6) Inlet valve closes when crank has moved through 210 degrees from head-end dead centre.
(7) Ignition takes place when crank has moved through about 330 to 340 degrees from head-end dead centre.
(8) Exhaust valve opens when crank has moved through 490 degrees from head-end dead centre.

The line diagram (Fig. 67) for four strokes shows this position

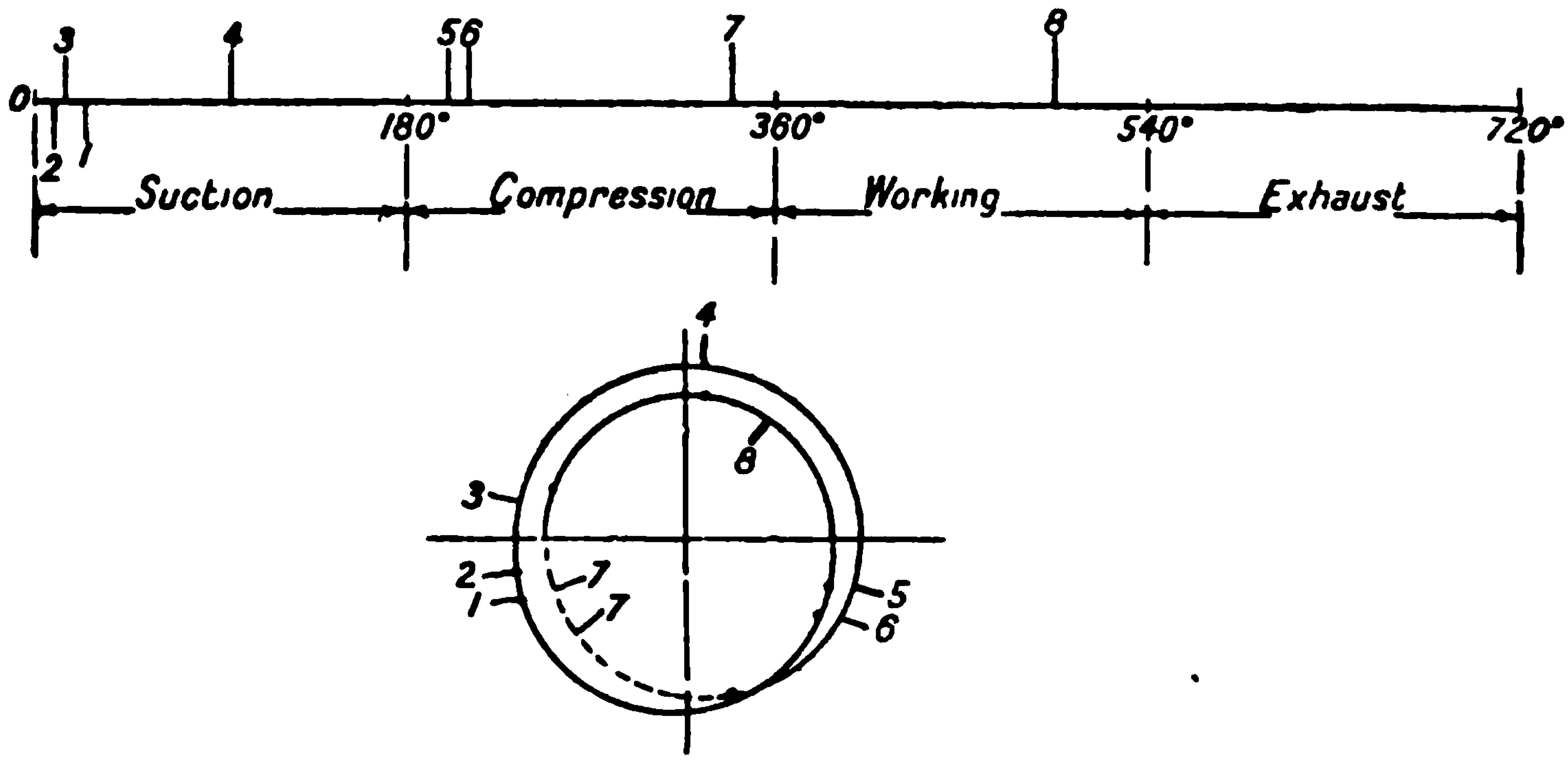

FIG. 67.
LINE DIAGRAM FOR TIMING.

starting at (1). Twenty degrees off the ignition time will decrease the capacity of an engine at least one-third.

D. **Overheating** is usually caused by the cooling water liming up the jacket passages; this has been dealt with in cooling water systems. When the cylinder becomes overheated, the oil does not lubricate, but burns off on the cylinder and piston. If the pistons are tight fitting and not water-cooled, the excessive temperature expands them enough to stick in the cylinder, and if allowed to continue will gradually stop the engine. Many a large breakdown followed by a long stop for repairs has been caused by working the engine with defective cooling or scant water supply.

The other case of heating cited here, namely, heating of bearings, has also been dealt with, but there is a point which is sometimes overlooked in vertical engines driving a dynamo which is mounted on the same bedplate as the engine, and that is magnetic pull. The sides of the bearing first become hot and wear down very fast, causing side play, due to the pull on the shaft. In some cases it has been found necessary to ask the makers to extend the shaft so that field coils could be shifted along the bedplate. The end wear can be taken up by placing white-metal on the face of the flanges of the brasses. This is a trouble which should not occur, but which has caused an attendant much worry and the engine to lose power.

Misfiring.—Power loss is generally accompanied by misfiring, and as a wrong mixture will cause loss of power it usually leads to misfiring. Theoretically, for natural gas, a proportion of 9 parts of air to 1 part of gas (approximately) by volume is required. The attendant will only require to make small alterations to avoid misfiring due to improper mixture. On engines using quality governing the mixture varies from a quality which is too lean to fire at light loads to one which is too rich to fire at heavy overloads. The governor should be set so that the maximum economic mixture will be reached at rated engine capacity, with a correspondingly lean mixture at light loads.

The mixture in engines using quantitative governing is usually adjusted by the attendant, and he should aim at keeping the mixture as lean as possible. This is approximately reached when a good blue flame is obtained by placing a light to the open firing cock. This mixture may require to be enriched at heavy loads. Analysis of exhaust gases and consideration of the way the engine carries out its work as shown by the indicator cards form the best guides for adjusting the mixture.

Misfiring in one cylinder of a multi-cylinder engine is caused by that cylinder gathering a heavy carbon deposit, by an air leak, sooty plug, loose wire, or stuck vibrator. A fault in one cylinder throws the whole engine out of tune.

E. **Sudden Stop.**—The most likely causes for sudden stoppage are :—

(1) Ignition switch jarring out.
(2) Fuel finished in tank.
(3) Broken wire or loose connection.
(4) Carburetter nozzle clogged with dirt.
(5) Fuel pipe leading to carburetter clogged.
(6) Timer broken.
(7) Hot bearings.

(8) Defective ignition.
(9) Water in fuel.
(10) Lubrication failing and piston seizing.
(11) Poor mixture.

These faults can nearly all be avoided with proper care and cleaning, and the remedy is not difficult to employ. The sudden stop is most likely to lead to other troubles, and, before starting up, the engine must be carefully examined, oiled, relieved of load, and barred round.

F. **Backfiring and Pre-ignition.**—These two troubles the attendant on a gas or oil engine must always be ready to overcome. They are both alike in their results—loss of engine power—though dissimilar in their action. The one is noisy and alarming but harmless; the other is silent but dangerous.

Backfiring is a burning of the charge during the time the exhaust ports remain open, and sometimes occurs in the exhaust pipe and at other times in the cylinder. It begins wherever a fresh charge of combustible fuel comes in contact with the burning products of the previous combustion. A later combustion than usual, a very slow burning mixture, an overloaded engine running slowly with a wide, open throttle, a late opening of the exhaust valves or ports, a choked exhaust—these are all very apt to create backfiring. With retarded spark, weak battery, or defective timer, causing a complete misfire, the fresh charge, compressed in vain and then expanded, is swept into the exhaust by the incoming charge without energy of its own. Remaining in the vicinity of the exhaust, it is ignited readily by the products of the next explosion, causing a terrific bang without affecting the engine further.

By *pre-ignition* is meant a premature explosion of the charge in the cylinder after the exhaust ports are closed and before the normal ignition should take place. This trouble is chiefly caused by contact of the charge with some incandescent object in the cylinder. Carbon deposit, caused by too much lubricant (or a rich fuel mixture), sharp edges of nuts, of valve seats or of firing plugs—any or all of these may heat up sufficiently to fire the charge. Chips of wood, straw or waste, which are quickly carbonised into a deposit on the cylinder walls, glow up afresh with each stroke and cause pre-ignition. The remedy for this last cause is to filter both fuel and lubricating oil or wash the producer gas carefully. Pre-ignitions are to be dreaded, not so much for loss of power, but on account of the abnormal stresses set up in all the principal moving parts of the engine. The degree of danger depends upon the point of stroke at which pre-ignition takes place.

Cases of pre-ignition have been known to take place in vertical

engines due to a thin film of oil being able to creep along the piston, the rings having gaps in one straight line along the axis of the piston. The oil becomes vaporised, and this is increased during the suction stroke, so that the combustible mixture is composed of vaporised oil, producer gas, and air. The oil burns before the period set for the producer gas, and this ignition of oil burns the gas before its proper time, creating a violent kick and backfire. The gas engine has almost been converted into a liquid fuel engine operating on the self-ignition principle, the oil being in sufficient quantities to cause pre-ignition.

G. **Irregular Running.**—Irregularity of speed is frequently due to worn contacts between the governor and valve mechanism, worn make-and-break mechanism, such as loose joints, weak or broken exhaust valve springs, worn cams or cam shafts on multi-cylinder engines, as well as a twisted shaft or a loose gear wheel. It may be caused by incorrect mixture; but if this is correct, ignition is properly timed, and the general mechanical condition of the engine is good, the irregular running is probably due to the loading of the engine beyond its rated power.

H. **Overheating in Cylinder.**—This is caused by poor water supply (see Cooling System), poor compression and insufficient valve lift, clogging in exhaust pipe, a clogged silencer or radiator, or overloading the engine. These can all be avoided by efficient, watchful care and attendance and heeding the old warning given by all engine makers—keep the engine clean and in good repair.

I. **Crank-case Explosions—Two-cycle.**—These explosions are dangerous and the cause should be removed at once. Working with too lean a mixture gives rise to crank case firing (equivalent to backfiring in four-stroke cycle engines), due to the weak mixture lighting back into the crank case. The remedy is to increase the richness of the gas, either by increasing the tension on the auxiliary air valve spring or by adjusting the needle valve so as to increase the flow of the fuel. These two-cycle engines often miss every other revolution regularly, or, as it is often called, "four-cycle." This is caused by too rich a mixture; the auxiliary air valve requires to be opened. The adjustment should give a mean between these two conditions. A retarded spark is very apt to cause these crank case explosions.

J. **Smoke.**—Black smoke calls for the adjustment of the fuel valve until the smoke ceases and misfiring stops on low speeds. A correct adjustment of the mixture is required until the engine runs smoothly without smoke.

Light-coloured smoke at the exhaust pipe indicates an excess of

cylinder oil, and in the case of a multi-cylinder engine indicates that one cylinder is being supplied with too much oil, due to one crank case having become flooded with oil. In this case the attendant may find that the overflow pipe has become clogged, allowing a high level of oil in this one compartment.

K. **Engine Gradually Slowing Down.**—This is caused by—

(*a*) Weak or exhausted battery or magneto slipping, or the governor may be out of order.

(*b*) Overloaded engine or overheated bearings.

These require no further comments.

L. **Excessive Vibration.**—An engine crank shaft which is not in perfect balance will cause the whole engine to go badly out of tune by setting up vibrations in the engine frame. If this is not attended to, the foundation is likely to become affected. Faulty balance is not so often met with as formerly, as balance weights are nicely adjusted to suit the weight of crankshaft webs. Twist on a camshaft will cause a change in valve timing and make for uneven application of power. The same effect is caused by uneven wear on cams and push rods. In fact, anything which causes disarrangement of timing gear will make for excessive vibration in the engine.

M. **Wheezing, Scraping Sound.**—The cause of this may be looked for in one of the following :—

(1) A broken piston ring.

(2) A piston dried through lack of oil or due to overheating or tight piston rings.

Sometimes, through the guard sagging or having been pushed from the perpendicular, the flywheel may start rubbing on this metal shield.

N. **Knocking or Pounding.**—Should pounding occur at regular intervals, it may be put down to the fault of ignition, the timing being too far in advance. An overheated cylinder has something of the same effect, and, of course, pre-ignition will cause pounding.

Loose main bearings and connections will cause knocking to take place. Wear should be taken up as soon as possible, and this is better done at regular intervals than left until knocking is heard. Slack bearings mean worn pins as well as noise ; oval piston or gudgeon pins waste lubrication. Make sure that the flywheel is keyed tightly, that no movement, however slight, can take place between the flywheel boss and the shaft. If the crankshaft is taken out of place, always make this an opportunity to check for alignment of shaft bearings.

Loose counter-weights and end play in shaft must be attended to, as these cause regular knocking. In the case of a broken valve stem a regular knocking will indicate the trouble.

Irregular knocking can be caused by loose electric connections, loose piping or rods on the engine, and also by pre-ignition.

As will be seen, there are many small details which cause minor troubles, most of which, with care, can be avoided. Just as in any other class of machinery, there are troubles which cannot be so easily got rid of. Surface cracks in forgings may pass even the most rigid inspection, and such forgings work as part of an engine until a severe shock, such as a pre-ignition, causes the part to fail by being stressed beyond normal.

Crankshafts give way at the junction of the crankpin and web or at the journal and web. The spring test which is applied to shafts usually saves a bad one from being sent out of the works by the engine makers.

Slack flywheel keys have a result similar to that of a suddenly applied load. Instead of the load being smoothly transmitted from the piston to the flywheel rim and then back again to the driving pulley, the slight movement results in a series of blows which, because of their suddenness, stress the shaft beyond the normal working stress.

Connecting rod bolts, due to repeated loadings, break down. It is recommended that these be annealed at least each year, as this minimises the risk of fracture, which often causes the wreck of gas and oil engines. Should the connecting rod start to knock there are extra stresses set up in the bolts. These bolts are best renewed, say, every three years, especially in small engines.

Frost accidents.—During periods of frost it is advisable, if the engine is standing during any length of time, to drain the jackets, care being taken that the water inlet valve is not leaking, or a small leak of water may find its way into the jacket and get frozen up.

Accidents during repair.—All parts made of cast iron, if not carefully handled, are readily broken. One of the most common breakages is the mouth of the piston. The connecting rod must never be allowed to swing on the piston during repairs, since this may break a piece out from the front edge of the piston. Cast-iron valve levers do not, as a rule, lie flat on the engine-room floor, and they are easily broken during repairs. Oval flanges can be cracked by screwing up the bolts too tightly when making a new joint.

Inspection and *insurance* of gas and oil engines can be effected through a boiler and engine insurance company, and the owner of the engine has the satisfaction of knowing that he has the engine covered for ordinary breakages. The attendant may also be guided in his work and made to carry out cleaning carefully, since he knows that his work has to be examined by a proficient inspector.

CHAPTER XIII

INDICATOR CARDS

THE study of the indicator cards, which in power stations are usually taken every week, will often reveal irregular action of the engine. The pressure at various points of the stroke of the engine piston is obtained from the cards, and by means of these a value for the mean

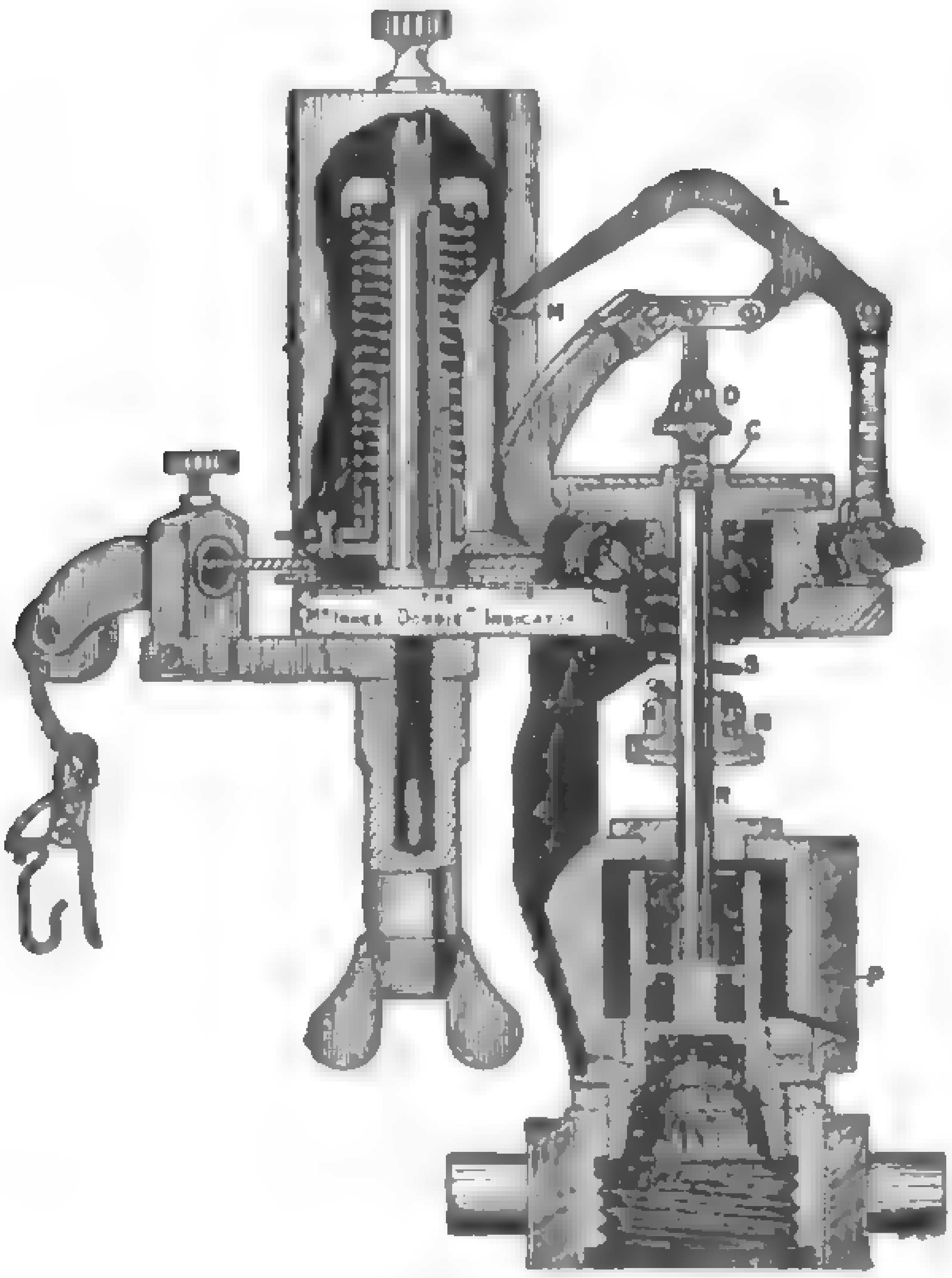

FIG. 68.
MCINNES-DOBBIE INDICATOR.

effective pressure can be obtained, and therefore the indicated horse-power, as the area of the card represents graphically the work done in the cylinder.

A McInnes-Dobbie indicator (Fig. 68) consists of a small pressure cylinder in which a piston is made to work against the pressure of an

external spring (not subjected to the heat of gases) of known compression strength. At the end of a system of levers, which magnifies the motion of the indicator piston six times, is placed a pencil. The travel of the indicator piston depends on the pressure in the engine cylinder. An indicator diagram is about 3 in. long, and as this is a copy of the stroke of the engine to scale, the motion given to the drum on which an indicator card paper has been placed must be a reduced motion of the engine piston. A reducing gear is used which is usually supplied by the engine makers, and is made up of two or

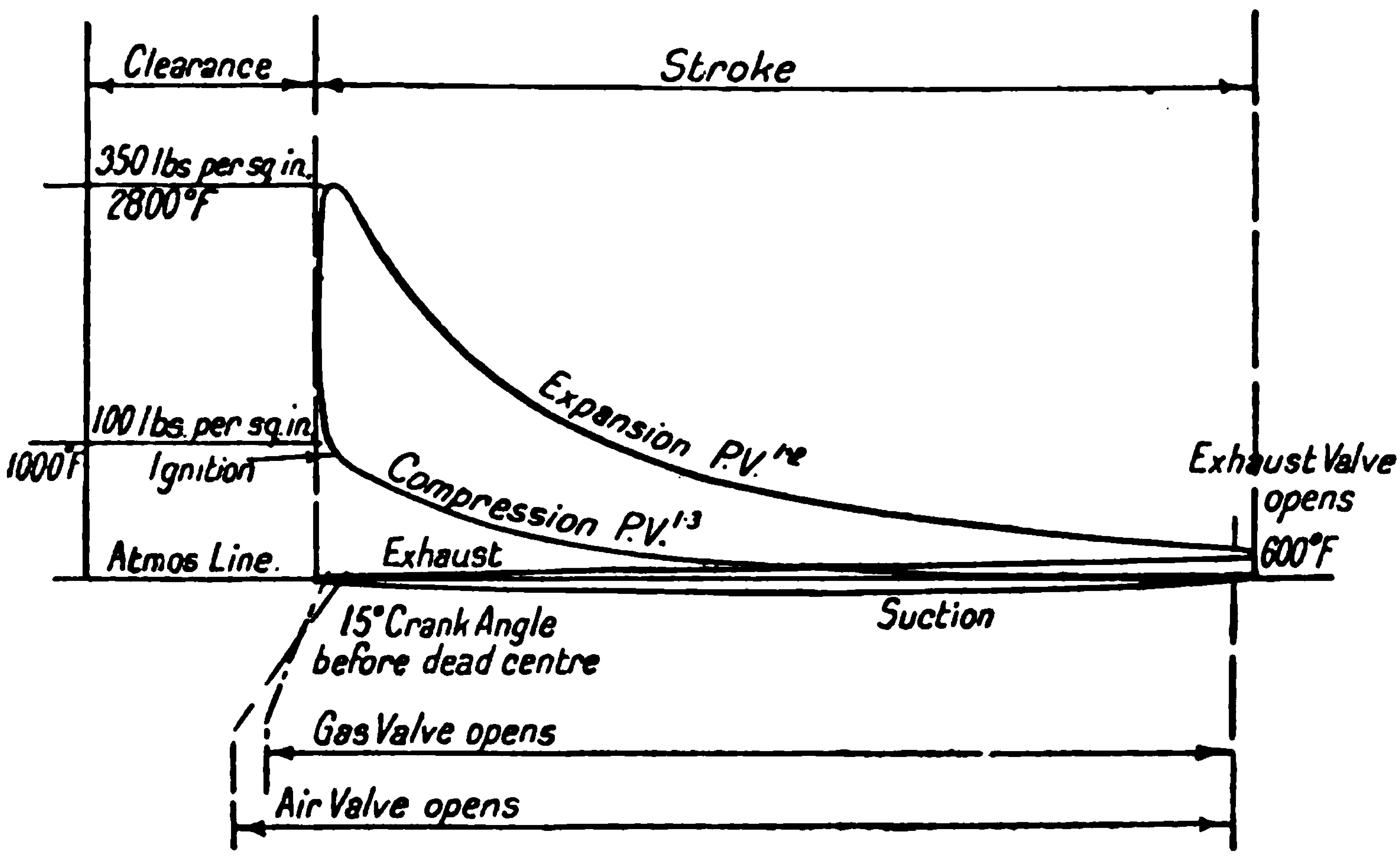

FIG. 69.

INDICATOR CARD TRACED FROM OPTICAL INDICATOR.

three simple levers, one of which is in the form of a sector of a light-grooved pulley, from which a cord is led to the indicator drum. The to-and-fro motion of the piston thus causes the cord to have the same motion to a reduced scale. This gives the length to the indicator card.

With engines running about 250 revolutions per minute it is found difficult to manipulate the usual indicator mechanism, and an optical indicator is often used. From an optical indicator screen a photo of the card is taken on a plate, and prints can be made by hand. Fig. 69 is traced from such a plate taken from a gas engine, and shows the usual pressures and temperatures (approximately). The attendant will readily understand how the cylinder and piston lubrication

becomes difficult when working with gases between the temperatures of 2800° F. and 600° F. Approximate clearance volume is seen to be

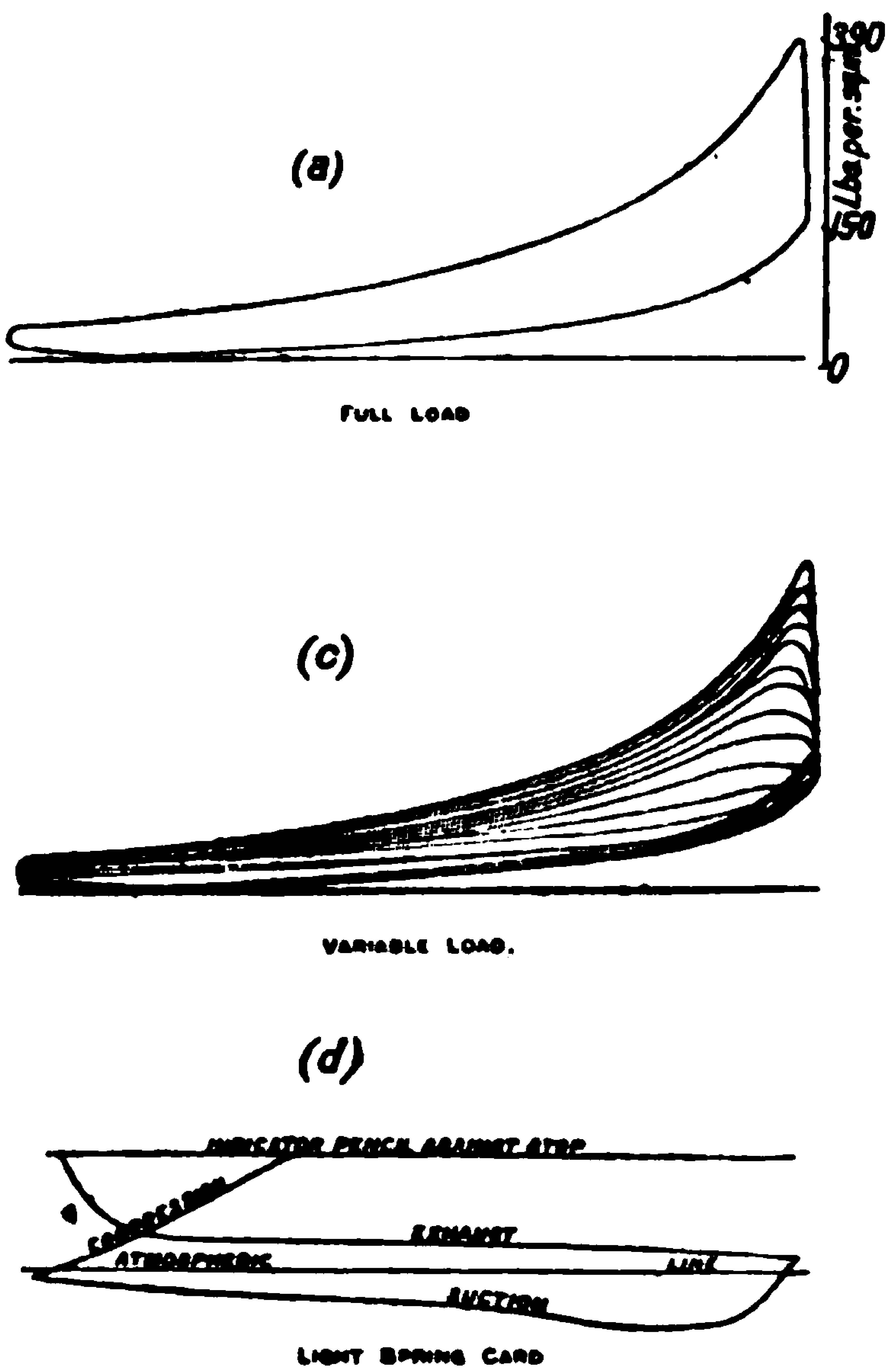

FIG. 70.

INDICATOR CARDS:

(*a*) FULL LOAD; (*c*) VARIABLE LOADING; (*d*) LIGHT SPRING DIAGRAM.

about 25 per cent. of the volume swept by the piston. On the diagram has been marked the valve opening and closing positions, and also

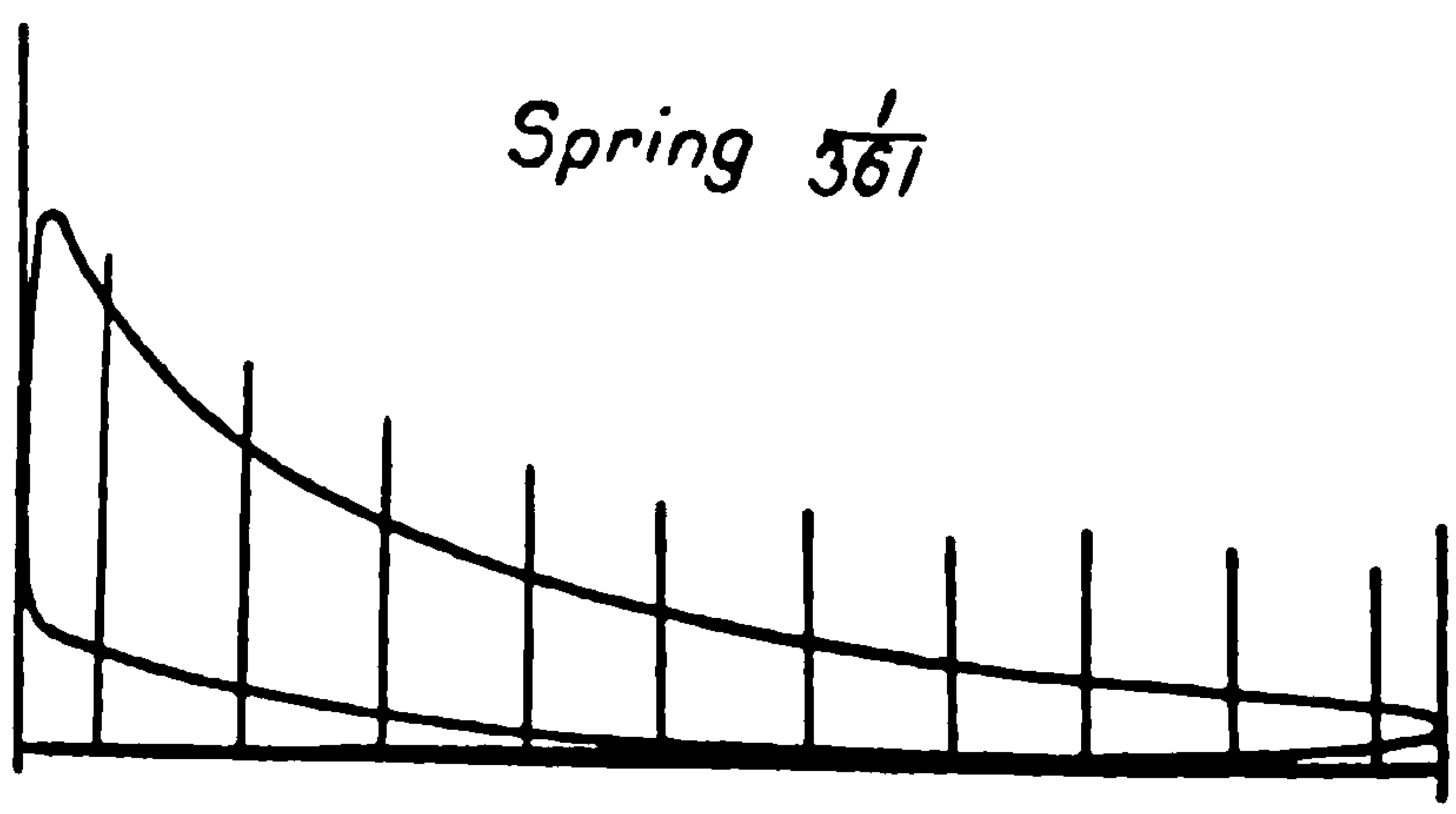

FIG. 71.

NATIONAL GAS ENGINE CARD DIVIDED BY TEN MID-ORDINATES.

approximate values have been given to the expansion and compression curves, which closely follow the P.V. law.

Typical indicator cards are shown in Fig. 70 ; (*a*) was taken at full load (nearly). The compression pressure will be noticed to be about 150 lb. per square inch, and the maximum pressure about 390 lb. per square inch. This card shows very rapid combustion on producer gas, and is almost a perfect card. The light spring diagram (*d*) shows

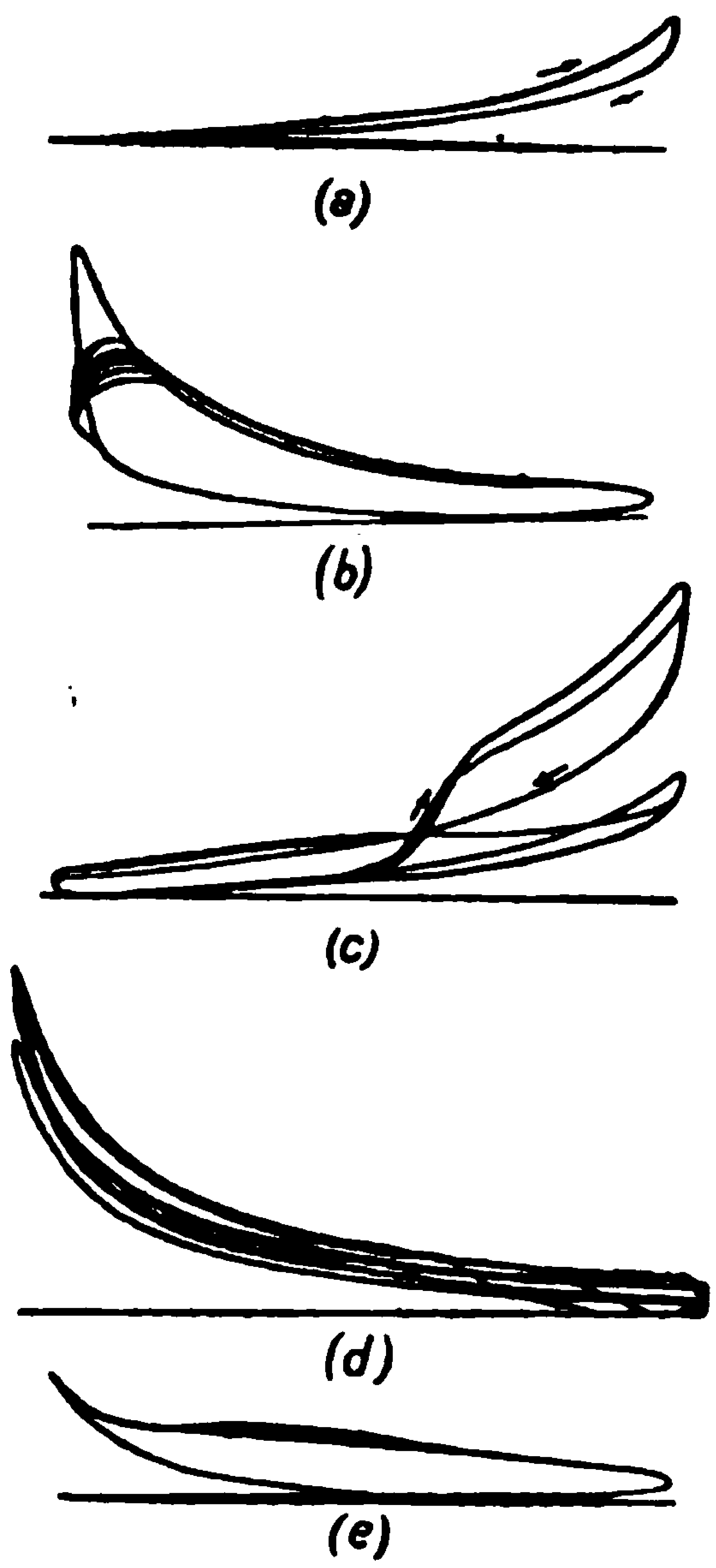

FIG. 72.

CARDS SHOWING ENGINE FAULTS.

clearly the suction, exhaust, and beginning of compression strokes. This diagram has the advantage of showing how the pressure during the suction stroke falls below the atmospheric line, and the compression line cuts the atmospheric line after the piston has travelled about 6 per cent. of the stroke on the compression stroke. The variable load diagram (*c*) was obtained in conjunction with a variable-admission governor, and represents twelve different loadings of the engine.

The diagram is divided up by ten mid-ordinates, from which the mean ordinate can be found, and the product of this mean ordinate

length in inches and the spring number 360 gives the mean effective pressure (M.E.P.). This was done in the case of the National engine as tested (Fig. 71) and the M.E.P. used to obtain the indicated horsepower of the engine.

Examples of defects of engine working shown on indicator cards

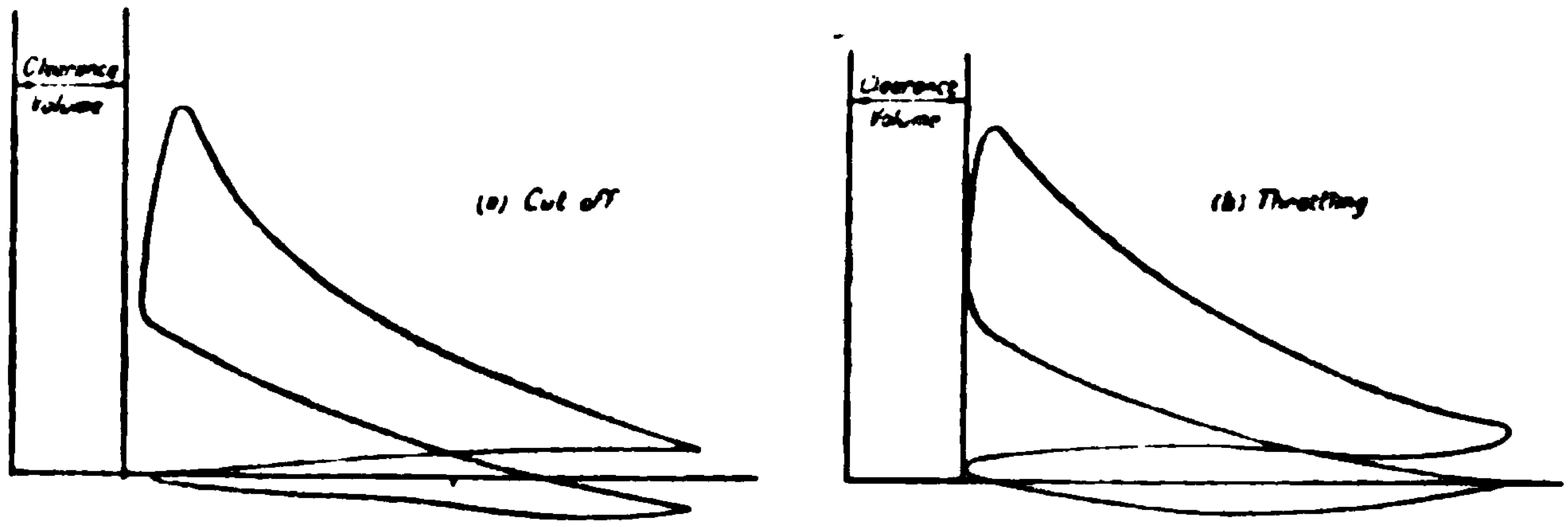

Fig. 73.

Cards showing Effect of Governing.

will repay a careful study, and the following are from engines working on the "Otto" cycle. Referring to Fig. 72,

(*a*) Is a compression diagram, but the expansion line falling considerably below the compression line indicates leaking piston rings.

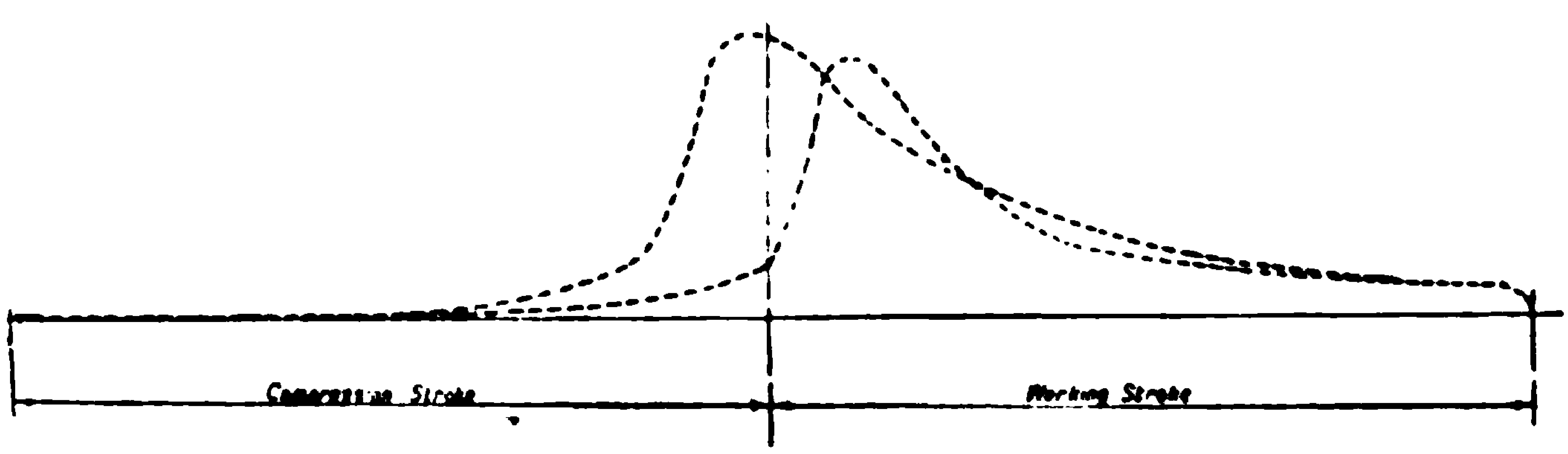

Fig. 74.

Card showing Pre-ignition.

(*b*) Taken from an engine on producer gas shows clearly that slow burning takes place during one stroke, causing pre-ignition with unburnt fuel.

(*c*) This irregular indicator card, taken from a double-acting engine,

was caused by leakage past the piston sufficient to ignite the charge during compression and to raise the pressure during exhaust and admission.

(*d*) Shows very clearly pre-ignition from the hot carbon deposits, indicating dirty pistons and valves.

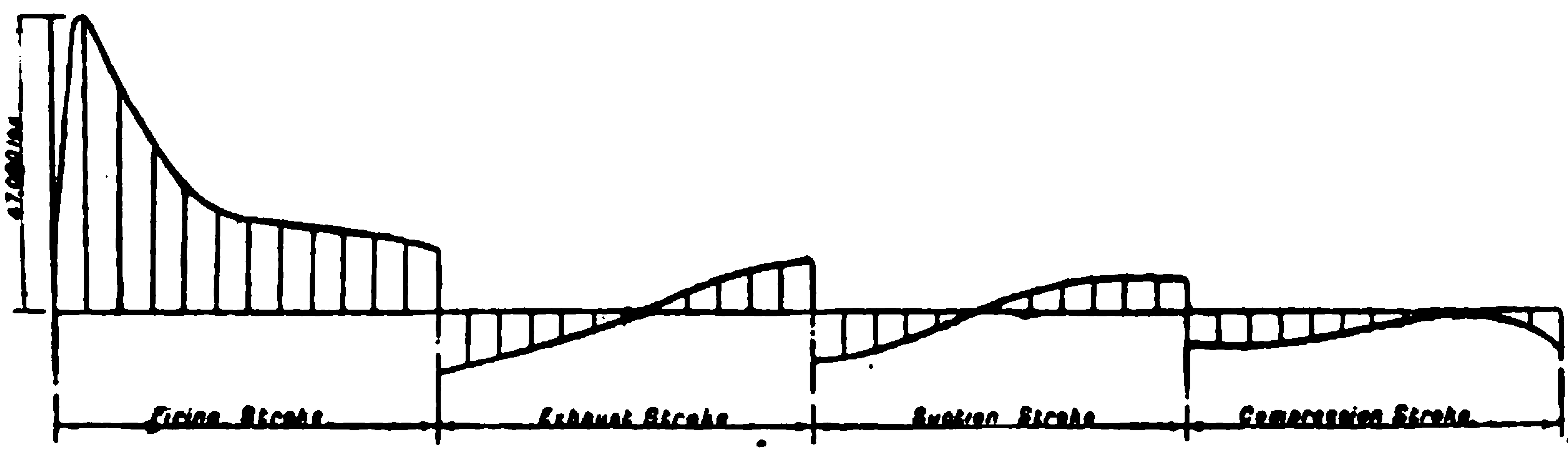

FIG. 75.
EFFECTIVE FORCE DIAGRAM.

(*e*) Is caused by late ignition, combustion taking place after the piston has started forward.

Experience has shown that ignition must occur before the end of the compression stroke in all engines in order that combustion may be nearly completed by the time the expansion curve starts. Much

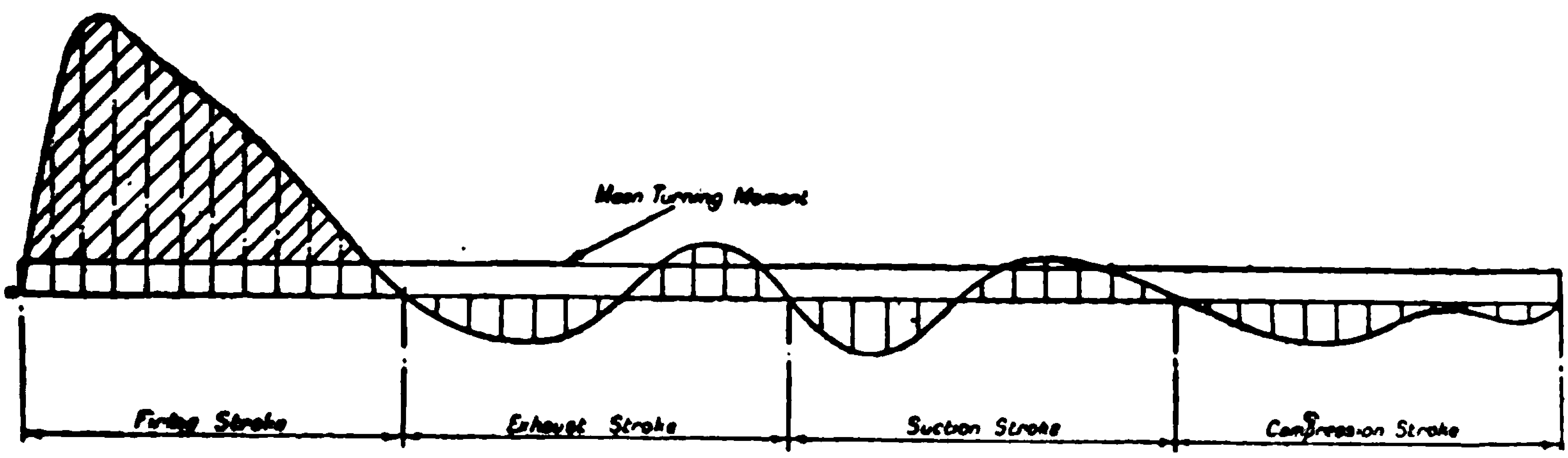

FIG. 76.
TURNING MOMENT DIAGRAM.

hydrogen or light hydrocarbons in the fuel necessitates a late ignition, and when much carbon monoxide (CO) is present a much earlier ignition is required.

The effect of governing is shown in the two diagrams (Fig. 73). In the left-hand diagram the mixture of gas and air is cut off before the end of the stroke and goes on expanding until the piston reaches the end of this suction stroke. In the right-hand diagram from the

beginning of the suction stroke a smaller quantity than normal is taken and continues to flow into the cylinder until the end of the suction stroke. This is called throttling the supply. The diagrams show how effective the use of an indicator is in the tracing of any change which is made in the cylinder supply. It also shows how the negative work increases by the lower loop of the diagram growing larger than it would be in the normal indicator card, and also how the compression pressure falls due to the smaller quantity of gas and air being received into the cylinder than is the case in the normal running engine on full supply.

An indicator card showing pre-ignition placed on the same diagram as a normal card, and also a diagram of effective force on the piston, are shown (Fig. 74). It will be seen that the negative forces or backward forces tending to stop the engine are nearly as great as the forces which are endeavouring to drive the engine round. It is not the force on the piston with which the attendant is most interested, but the effort which the engine puts out to do work at the crankshaft. The effective force diagram for a gas engine running at, say, 200 revolutions per minute will have a shape as shown in Fig. 75. This diagram shows the function of the flywheel, which has to store energy during the working or explosion stroke to carry the engine through the suction, compression and exhaust strokes. The mean turning moment for this gas engine is shown (Fig. 76), and the engine working at 200 revolutions per minute had a cyclic irregularity value of less than 5 per cent.—that is, the speed varied between the limits of 204 and 196 revolutions per minute.

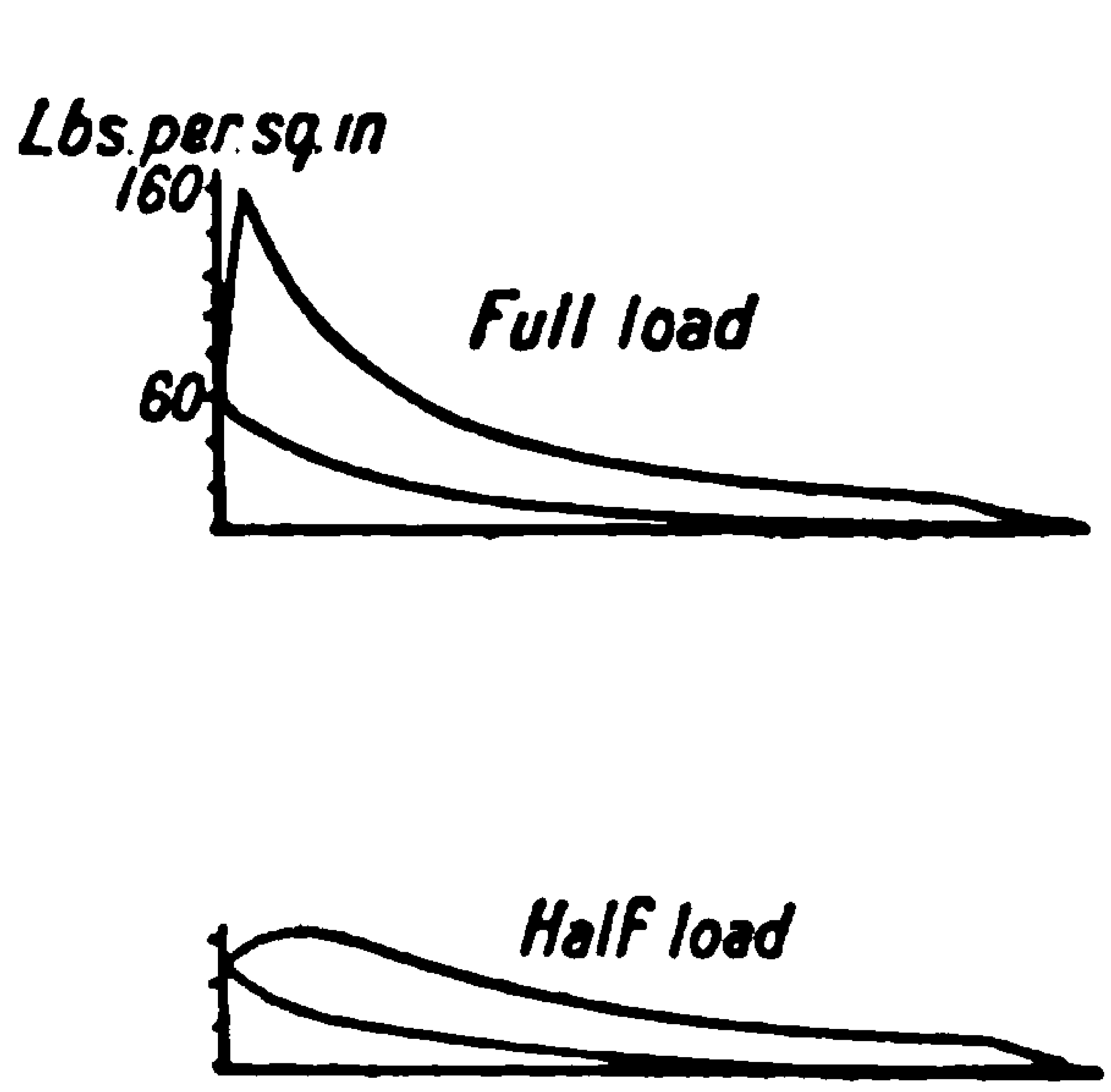

FIG. 77.

CARDS FROM BESSEMER ENGINE (HALF AND FULL LOADS).

The diagram (Fig. 77), taken from a two-stroke cycle (single-cylinder Bessemer) engine, is reproduced here, showing a full and a half load card. Compare the release point with some of the previous diagrams taken from engines with exhaust valves. This break away from the rounded release point is peculiar to all central exhaust engines. The engine works at 180 revolutions per minute, and has a cylinder 16 in. in diameter with 20 in. stroke, and at this speed, with natural oil well gas, transmitted 70 brake horse-power. In the half-load diagram the combustion line slopes forward, showing retarded combustion, due, probably, to the incoming fresh gas being very

much diluted with the exhaust gases or burnt gases left in the cylinder.

Indicator diagrams from an Oschelhauser engine are shown in Fig. 78, and along with them is shown a piston load curve and an inertia of parts curve from the same engine. It will be seen that the long compression curve for this class of engine nearly compensates

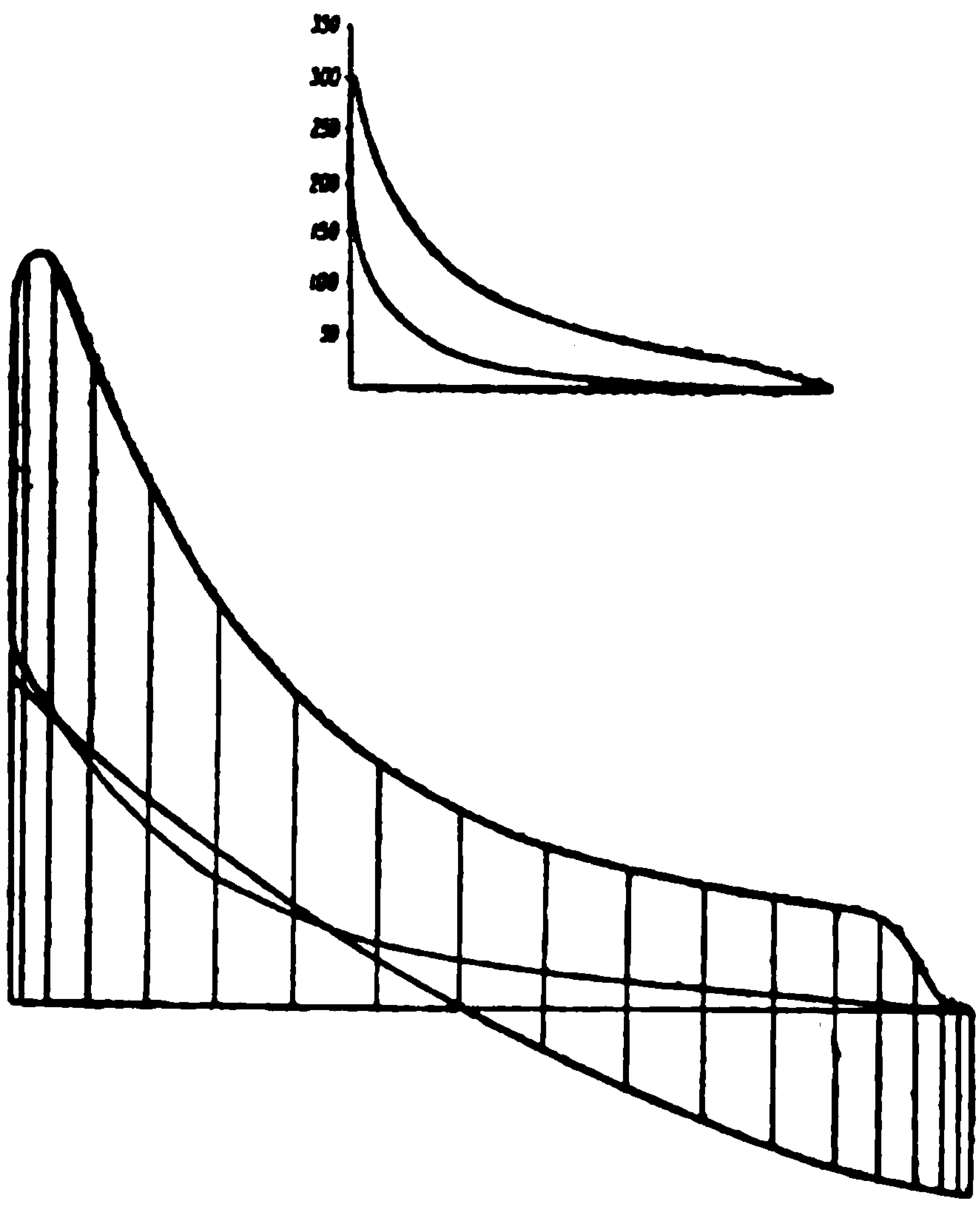

FIG. 78.

CARDS FROM OSCHELHAUSER ENGINE.

the inertia of parts, and thus ensures smooth running over the dead centres.

From the foregoing the attendant will see that the indicator card gives a means of studying the way in which an engine is performing its work and using its supply of fuel. It shows if the valves and governor are performing their various functions at the proper time, and, along with the other diagrams, should help in the tuning up of the engine to suit given conditions of working.

CHAPTER XIV

METHODS OF TESTING AND RESULTS OF TESTS

Object of Tests.—When the size of the engine permits, tests are usually made in the factory to ascertain the proper setting of the governor for speed regulation, the correct timing of the ignition apparatus, the correct amount of compression, the proper timing of the valves, and also to see that there are no defects in the material used in the construction of the engine. When buying an engine, its engine-power must be known and the fuel consumption at full and fractional loads ; these the maker will guarantee.

In the laboratory still more exacting tests are carried out, so that an exact knowledge of certain classes of engines will be obtained and may be made use of in design. A heat balance is drawn up for producer and engine or for the oil engine. It is advisable to understand how such a test is carried through, and to notice the readings recorded and how these are used. The principal readings taken in a commercial test are :—

(1) Quantity of fuel supplied.
(2) Calorific value of fuel used.
(3) Indicated horse-power from indicator cards.
(4) Brake horse-power from brake readings.
(5) Quantity of jacket water.
(6) Entering and exit temperatures of jacket water.
(7) Air temperature.
(8) Fuel temperature at engine.
(9) Temperature of exhaust gases at engine.
(10) Barometric pressure.
(11) Pressure in gas and air pipes at engine.
(12) Speed of engine.
(13) Explosions in test.
(14) Variation of speed with change of load.

When the engine is using town gas the calorific value may be taken from the gasworks average value for the day of working, and the quantity measured by the meter, and the pressure by a U-tube

pressure gauge. Before using this quantity value it is usually converted to normal temperature and pressure (N.T.P.). When working with producer gas or oil the calorific values of samples of the coal or oil used is determined at regular intervals. Fuel gas analysis can be carried out to see that the fuel is being used in the very best manner. Great care must be taken in using the calorimeter, which has already been described. As mistakes are vital to the test results, too much care cannot be exercised in weighing coal or oil and treating of samples in the calorimeter. The quantity of gas from the producer may be passed through a Venturi meter, or in some cases the Pitot tube can be used along with measurements of pipes. In the case of large engines the gasholder is used as a measure of the quantity of gas made and used in a certain time. Measurement of brake horse-power in moderate-sized engines is carried out by means of a band brake. A diagrammatic sketch is here given (Fig. 79) of such

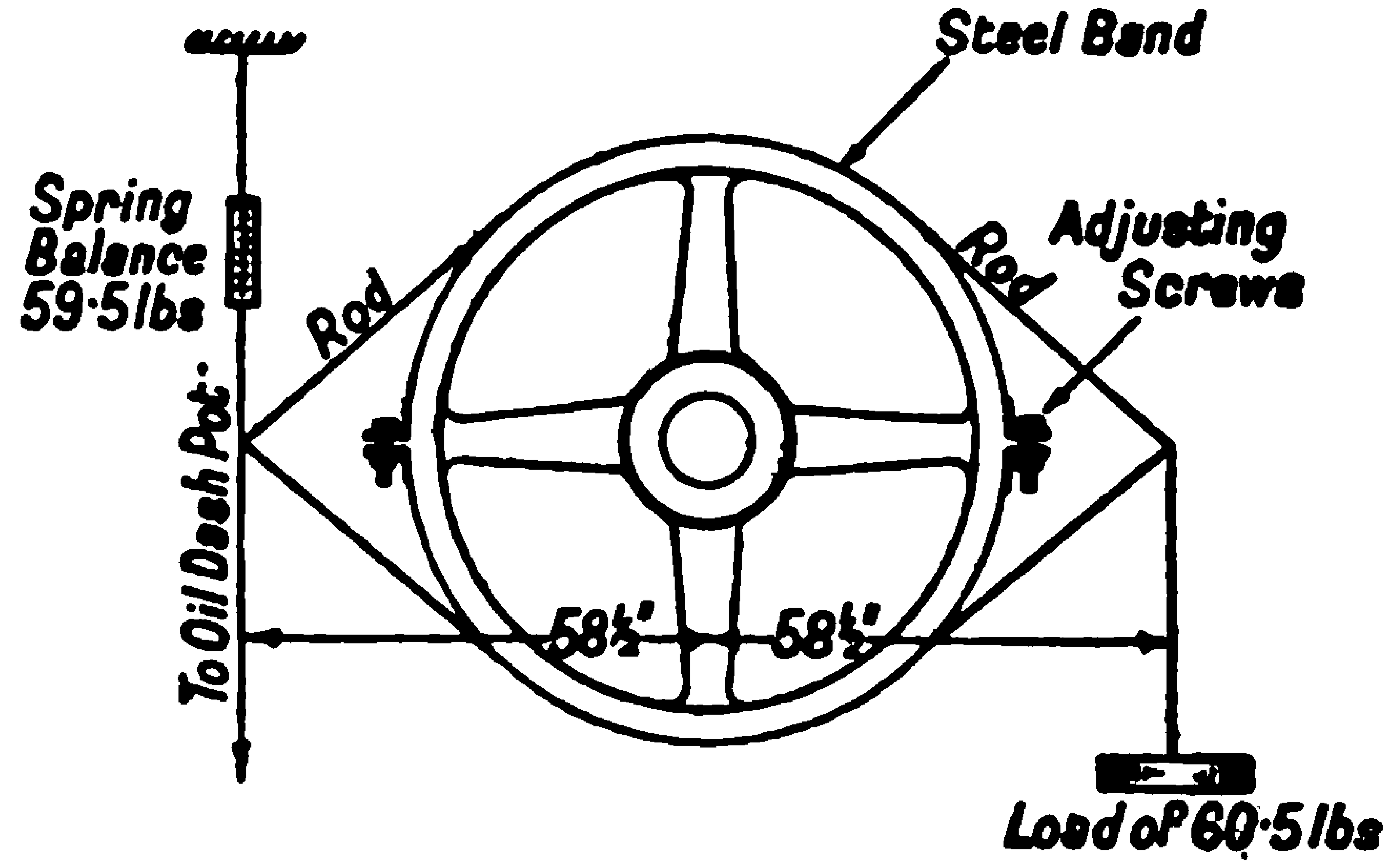

FIG. 79.
DIAGRAMMATIC SKETCH OF BRAKE.

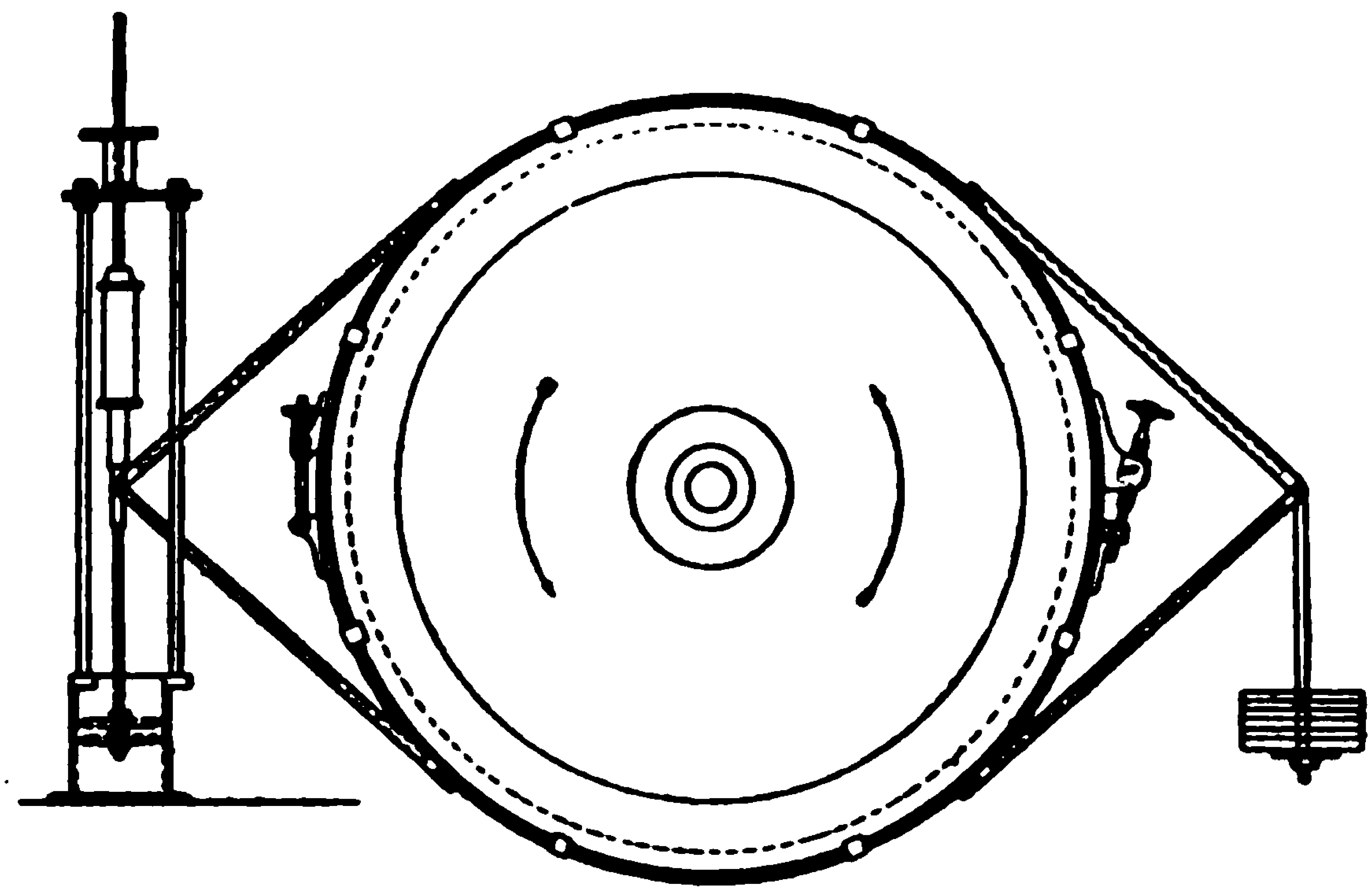

FIG. 80.
BRAKE USED ON NATIONAL GAS ENGINE.

a brake, and a more detailed sketch appears in Fig. 80. With large engines it is generally impossible to use the band brake, but by coupling up the engine to an electrical generator of known efficiency the power got out of the engine can be closely approximated.

The economy of engines is stated as a ratio of the fuel used for every one brake horse-power given out at the crankshaft per hour. It is more exact in the case of a gas to state the consumption in terms of B.T.U. consumed per developed horse-power hour (or kilowatt hour), stating a minimum calorific value below which the fuel should not fall.

Cyclic irregularity or governor regulation is generally stated as a percentage variation from normal speed. Many makers state that their engines will run with a speed variation from full to no-load of from 1½ to 2 per cent. *above* or *below* mean speed, and the engines can be made to run at 5 to 10 per cent. below normal speed to save wear and tear.

Makers of engines have published the following from time to time, and these figures are given as a guide to what might be expected.

First engine working on producer gas.

(*a*) At full load required 10,000 B.T.U. to 13,500 B.T.U. per B.H.P. per hour, and 75 to 100 cub. ft. of gas per B.H.P. per hour with 1·12 to 1·25 lb. of coal as fired.

(*b*) At three-quarters load, 11,000 to 13,000 B.T.U. per B.H.P. per hour.

(*c*) At half-load, 12,250 to 16,000 B.T.U. per B.H.P. per hour.

Second engine working on town gas.

(*a*) At full load, 10,000 to 13,000 B.T.U. per B.H.P. per hour; 15 to 20 cub. ft. of gas per B.H.P. per hour.

(*b*) At three-quarters load, 11,000 to 12,000 B.T.U. per B.H.P. per hour

(*c*) At half-load, 13,000 to 16,000 B.T.U. per B.H.P. per hour.

Third engine on blast furnace gas.

(*a*) At full load, 10,500 B.T.U. per B.H.P. per hour.

(*b*) At three-quarters load, 11,500 B.T.U. per B.H.P. per hour.

(*c*) At half-load, 13,000 B.T.U. per B.H.P. per hour.

Fourth engine on oil fuel.

(*a*) At full load, 8,720 B.T.U. to 13,320 B.T.U. per B.H.P. per hour; 0·393 lb. to 0·74 lb. per B.H.P. per hour.

At the Royal Technical College, Glasgow, the following tests were carried out by students:—

(1) Crossley gas engine test.

(2) National gas engine and producer test.
(3) Campbell oil engine test.

The summaries of these tests are given, but they are only to be treated as guides, and are in no way to be used as a comparison between the different makers' engines.

(1) Crossley gas engine (Fig. 7). The engine on which the test was made was a standard Crossley model, normally about 5 B.H.P. The dimensions are as follows: Diameter of cylinder, 5 in.; stroke 12 in. (ratio $\frac{d}{L} = \frac{5}{12} = \frac{1}{2 \cdot 4}$); flywheel used as a brake wheel is 3 ft. diameter. The igniter was heated by the ordinary Bunsen burner, and a hit-and-miss governor gear was in use. Glasgow Corporation gas was used during the test.

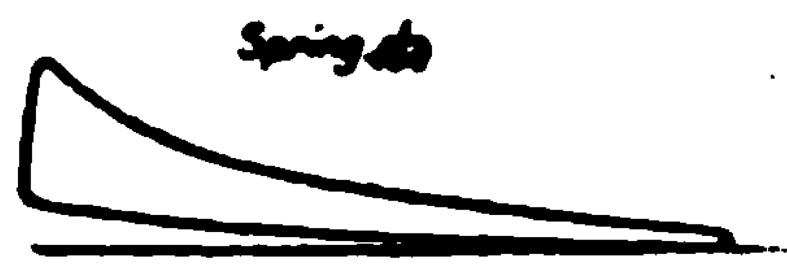

FIG. 81.
CARD FOR 5 B.H.P. ENGINE.

The object of the test was to determine the mechanical efficiency, the gas consumption, and also the thermal efficiency under constant load.

P = standard pressure absolute = 30″ mercury.
V = volume at N.T.P.
T = standard temperature absolute = 521° F.

Observed pressure, temperature, and volume are to be converted to suit N.T.P. by the formula—

$$V = \frac{P_1 V_1 \times T}{P \times T_1}$$

The cards are as shown in Fig. 81, and the springs used in the indicators are marked on cards.

Results are as follows :—

1	Number of test	1
2	Date of test	20/12/22
3	Duration of test	60 minutes.
4	Barometric pressure (inches of mercury)	29·78
5	Gas pressure (inches of water)	2·75
6	Gas pressure (inches of mercury, absolute)	29·98
7	Gas temperature (° F.)	63·2
8	Revolutions in test	15,424
9	Revolutions per minute	257
10	Explosions in test	5,584
11	Explosions per minute	93
12	Mean effective pressure, gross (lbs. per square inch)	88·8
13	Brake loads (W lbs.)	45·35
14	Brake loads (w lbs.)	5·25
15	Brake loads ($W - w$ lbs.)	40·1
16	I.H.P. (gross)	4·92

17	B.H.P.	2·93
18	Mechanical efficiency (per cent.)	63
19	Jacket water temperature (° F., inlet)	44·8
20	Jacket water temperature (° F., outlet)	93·6
21	Jacket water temperature (° F., difference)	48·8
22	Jacket water used in test (lbs.)	421·2
23	Jacket water used per minute (lbs.)	7·02
24	Total gas used in test (cubic feet)	88·11
25	Total gas used in test (cubic feet at N.T.P.)	85·5
26	Total gas used per hour	85·5
27	Total gas used per hour per I.H.P.	17·4
28	Total gas used per hour per B.H.P.	29
29	Gas used by burner (cubic feet per hour)	6·96
30	Gas used by burner (cubic feet per hour at N.T.P.)	6·55
31	Calorific value of gas (B.T.U per cubic foot at N.T.P.)	550
32	Temperature of exhaust gases (° F.)	580
33	Heat supplied by gas per minute (B.T.U.)	783
34	Heat to indicated work per minute (B.T.U.)	208
35	Heat to jacket water per minute (B.T.U.)	343
36	Heat to burner per minute (B.T.U.)	60
37	Heat to exhaust and radiation per minute (B.T.U.)	172
38	Thermal efficiency $= \left(\dfrac{\text{heat to indicated work}}{\text{heat supplied}} \times 100\right)$ (per cent.)	26·5

The engine is working at about ***half full load.*** The attendant should study these test figures along with the test figures given by the makers for a larger engine.

The same makers, Messrs. Crossley, in a test on a 160 B.H.P. engine, realised the following results, which are a set of really good results, with a carefully tuned-up engine having 21 in. diameter cylinder, 30-in. stroke and running at 170 R.P.M. on town gas of 550 B.T.U. per cubic foot.

B.H.P.	I.H.P.	Mechanical efficiency (per cent.)	Mean effective pressure. (lbs. per sq. inch.)	Gas consumption (cubic feet per B.H.P. per hour.) Calorific value 550.	Brake thermal efficiency (per cent.)	Indicated thermal efficiency (per cent.)
160 (full load)	186	86	90	15·7	30	35
80 (half load)	106	75	50	19·7	23	31
40 (quarter load)	66	60	32	27·7	17	28

From these results it will be noticed that at quarter full load the gas consumption per B.H.P. or developed horse-power is nearly double that at full power and that the efficiencies are nearly halved. This shows the engine to be much more efficient at full loads.

The details of another test carried out at the Royal Technical College, Glasgow, on a National gas engine and producer are given in tabular form. In tests (1) and (2) the engine was run on town gas, and in (3) on producer gas. Some particulars relating to the test of the producer are also given.

The engine is rated as a 40-B.H.P. engine working on producer gas at 200 R.P.M. Some particulars of the engine are here given: Cylinder diameter, 14 in.; stroke, 21 in.; "Otto" cycle single-cylinder and single acting; diameter of flywheel is 6 ft. and weighs approximately 2 tons. Bolted to the flywheel is a brake wheel-rim on which an adjustable steel brake band is fitted. This brake wheel weighs ¼ ton. On to the steel band are fixed arms which increase the effective radius of the brake, as shown in sketch (Fig. 80). The crankshaft with back balance weighs rather over ¾ ton, and the weight of the piston is approximately 300 lb. The connecting rod is about 370 lb. These approximate weights would act as a guide in lifting the several parts.

Test Number:—	1	2	3
Duration of test (minutes) . .	21	21	21
Revolutions per minute . .	214	209	205·5
Explosions per minute . .	49·1	70·5	57·4
Mean effective pressure (from cards)	106	99	70·3
Indicated horse-power . . .	42·5	56·6	33
Brake horse-power . . .	31·4	47·5	23
Mechanical efficiency (per cent.) .	74	84	70

Compare carefully tests (1) and (2).

The revolutions are about equal in both tests. Test (3) has eight more explosions per minute, yet the developed horse-power is about 8 H.P. greater in test (1) than in test (3). It is also seen that the mechanical efficiency is better for full-load test (2) than for test (1).

Test (3), of which only a few of the particulars are given in the previous table, was carried out at various running loads, but the figures given are for engine working on half load (approximately).

The object of the test was to determine the horse-power developed, mechanical efficiency, coal consumption, overall heat efficiency, and to draw up a heat balance.

Table of results is as follows :—

No.			Remarks.
1	Number of test	3	—
2	Date of test	25/1/23	—
3	Duration of test (minutes)	21	—
4	Barometric pressure (inches of mercury)	30·34	—
5	Temperature of gases leaving producer (° F.)	—	—
6	Weight of producer at start (lbs.)	44·5	—
7	Weight of producer at finish (lbs.)	29·5	—
8	Weight of dry combustible burned (lbs.)	15	—
9	Equivalent weight of dry coal burned (lbs.)	15·77	—
10	Dry coal used per hour (lbs.)	45	—
11	Dry coal used per square foot of producer section (lbs.)	14·3	—
12	Dry coal used per cubic foot of producer volume (lbs.)	5·55	—
13	Approximate analysis of coal (anthracite)	Dry.	Poor quality, owing to weathering.
14	Moisture, 2·3 per cent.	0	—
15	Volatile matter, 2·7 per cent.	2·75	—
16	Fixed carbon, 90·8 per cent.	92·5	—
17	Ash, 4·8 per cent.	4·89	—
18	Calorific value of wet coal (B.T.U. per lb.)	13,300	—
19	Calorific value of dry coal (B.T.U. per lb.)	13,000	—
20	Exhaust gas temperature (° F.)	611·5	—
21	Revolutions in test	4,312	—
22	Revolutions per minute	205	—
23	Explosions in test	1,207	—
24	Explosions per minute	57·4	—
25	Gross mean effective pressure (lbs. per square inch)	70·3	From indicator cards.
26	Gross indicated horse-power	33	—

No.			Remarks.
27	Brake load, weight end (lbs.) .	60·5	—
28	Brake load, spring end (lbs.). .	59·5	—
29	Brake horse-power . . .	23	—
30	Mechanical efficiency (per cent.) .	70	—
31	Dry coal per hour per I.H.P. .	1·37	—
32	Dry coal per hour per B.H.P. .	1·96	—
33	Overall heat efficiency (per cent.) .	10	—
34	Jacket water in test (lbs.) . .	310	—
35	Jacket water per hour (lbs.) . .	885	—
36	Inlet temperature of jacket water (° F.)	45	—
37	Outlet temperature of jacket water (° F.)	133	—
38	Heat to brake work (B.T.U. per lb. coal)	1,300	Developed work.
39	Heat to indicated work (B.T.U. per lb. coal)	1,865	—
40	Heat to engine friction (B.T.U. per lb. coal)	565	—
41	Heat to jacket water (B.T.U. per lb. coal)	1,730	—
42	Heat to engine exhaust, producer losses, radiation, etc. (B.T.U. per lb. coal)	9,705	—

The indicator card is shown (Fig. 82) divided up by ten mid-ordinates.

In the heat diagram (Fig. 83) the part (*a*) represents the amount

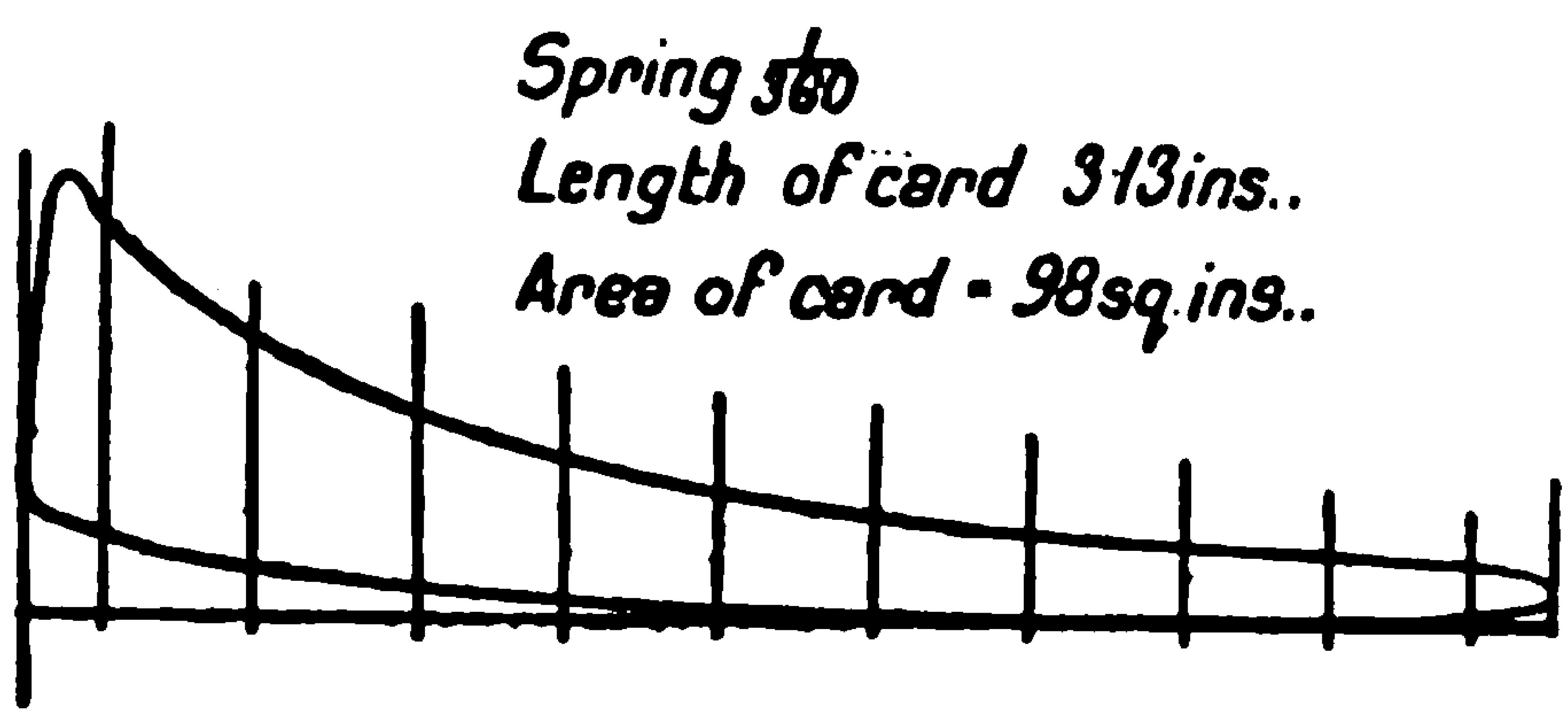

FIG. 82.

CARD FOR NATIONAL GAS ENGINE.

of heat given out as work developed by the engine; (*b*) is heat expended in work in moving the engine; (*c*) is heat given to jacket

water; (*d*) represents total losses other than (*b*) and (*c*). The whole diagram represents the heat in the fuel. It will be seen that heat spent in doing useful work is only 10 per cent. of the whole. Heat in (*c*) may be partly recovered by using the heated water to raise steam.

An oil engine test was made on a Campbell oil engine rated at 15

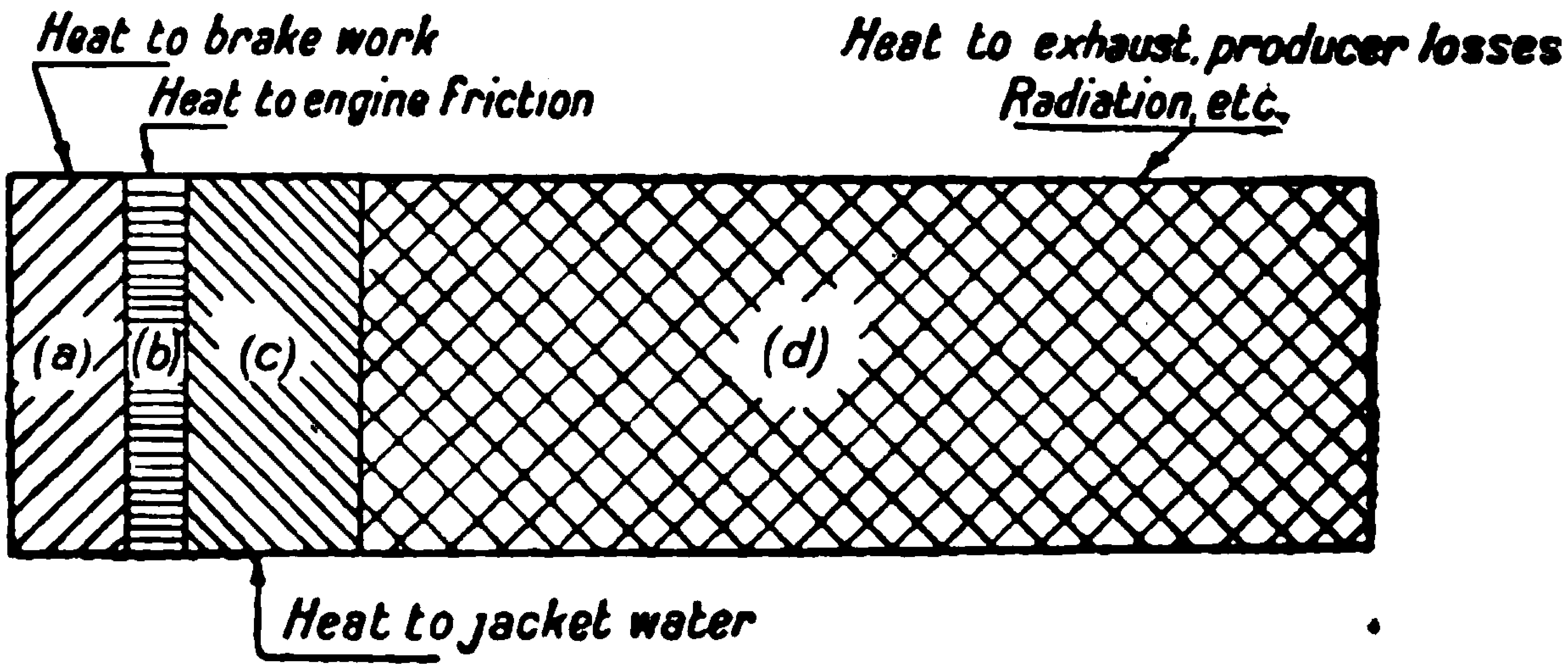

FIG. 83.

HEAT BALANCE DIAGRAM FOR NATIONAL GAS ENGINE.

B.H.P. at 250 R.P.M., shown in Fig. 32. Particulars of this engine are: Cylinder diameter, 8½ in.; stroke, 16 in.; flywheel diameter, approximately 4 ft.; and the brake was made of a cotton band belt. The oil used was paraffin.

Results :—

1	Test number	1
2	Revolutions per minute	260
3	Explosions per minute	72
4	I.H.P.	13·9
5	B.H.P.	10
6	Mechanical efficiency (per cent.)	70
7	Weight of oil to engine cylinders (lbs. per hour)	8·1
8	Weight of oil to burner (lbs. per hour)	0·7
9	Calorific value of oil (B.T.U.)	19,000
10	Oil per hour per I.H.P. (lbs.)	0·58
11	Oil per hour per B.H.P. (lbs.)	0·81
12	Heat to engine per minute (B.T.U.)	2,785
13	Heat to burner per minute (B.T.U.)	222
14	Heat to jacket water per minute (B.T.U.)	860
15	Heat to indicated work per minute (B.T.U.)	590
16	Heat to exhaust, radiation, etc. (B.T.U.)	1,113

17 Thermal efficiency $= \dfrac{\text{heat to indicated work}}{\text{heat to engine cylinder}}$
(per cent.) 23

18 Thermal efficiency $= \dfrac{\text{heat to indicated work}}{\text{total heat supplied}}$
(per cent.) . . . . 21·2

The heat-balance diagram is again shown (Fig. 84), and each part is given as a percentage. It will readily be seen how wasteful this form of ignition is, and, again, the great quantity of heat which is carried away by the necessary jacket water.

From the above tests it will be seen that the power obtained from

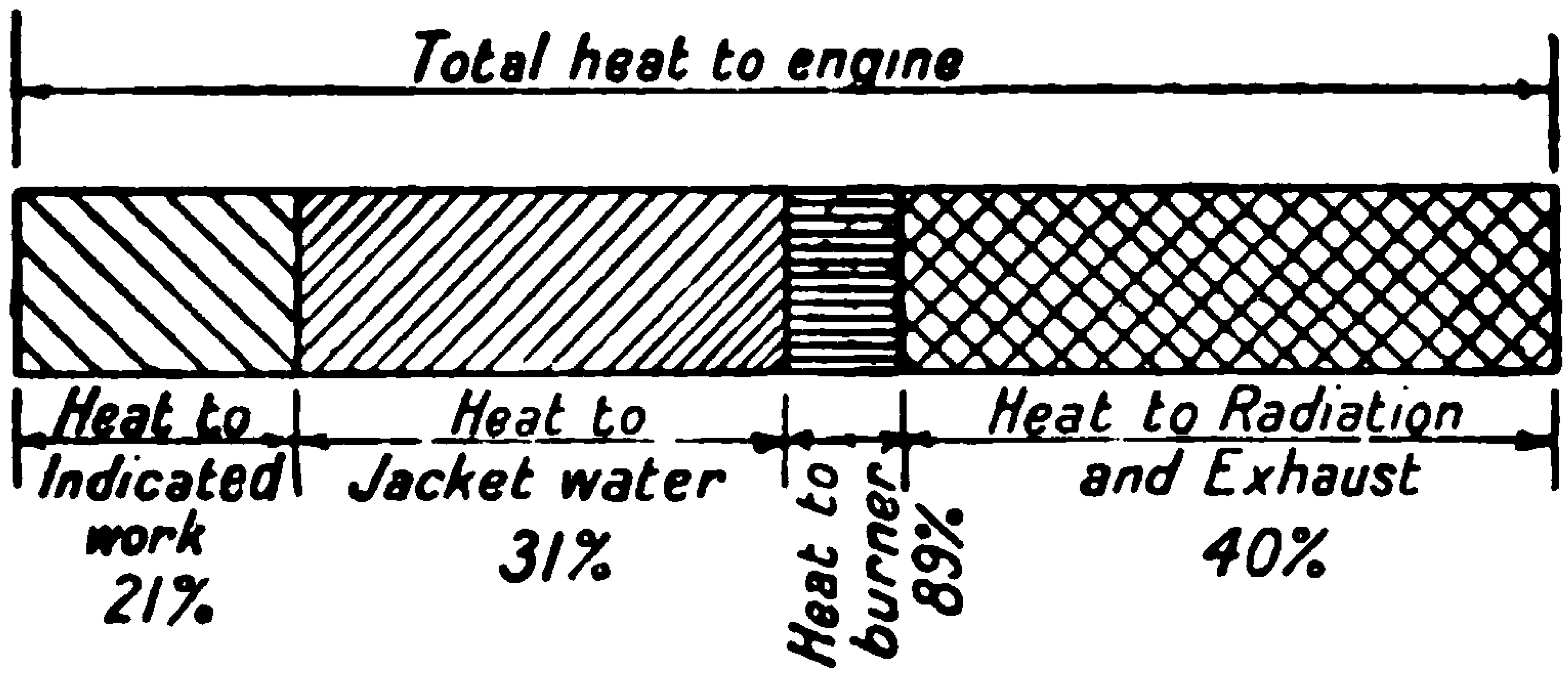

FIG. 84.

HEAT BALANCE DIAGRAM FOR CAMPBELL OIL ENGINE.

any fuel is determined by that portion of the heat developed by its combustion that may be transformed into work. In order to determine the heat balance, it was necessary to give or obtain the calorific value of the fuel to be used. The bomb calorimeter for coal testing has already been described, and it is proposed here to give a few figures from the test of a gas.

The following table on consumption of gas engines at various loads is well worth keeping for reference :—

Compression pressure (lbs. per square inch)	50	80	100	120	150
Gas consumption (B.T.U. per I.H.P. per hour at highest thermal efficiency)	12,700	9,100	8,200	7,600	7,100
Equivalent consumption in cubic feet per I.H.P. with gas at 500 B.T.U. per cubic foot	25·4	18·2	16·4	15·2	14·2
M.E.P. (lbs per square inch)	72	90	95	99	103·5

Full Load.	Mechanical efficiency (per cent.) .	81	84	85	86	86·4
	Cubic feet per B.H.P.-hour with gas of calorific value 500 B.T.U. per cubic foot. . . .	31·5	21·7	19·3	17·65	16·45
¾ Full Load.	Mechanical efficiency (per cent.) .	76	80	81	82	83
	Cubic feet per B.H.P.-hour with gas of calorific value 500 B.T.U. per cubic foot. . . .	33·5	21·7	20·2	18·5	17·1
½ Full Load.	Mechanical efficiency (per cent.) .	67	73	74	75	76
	Cubic feet per B.H.P.-hour with gas of calorific value 500 B.T.U. per cubic foot. . . .	37·5	24·9	22·2	19·75	18·7

In this table a standard of 500 B.T.U. for gas has been taken, but to suit local conditions of gas used the table can easily be changed as required.

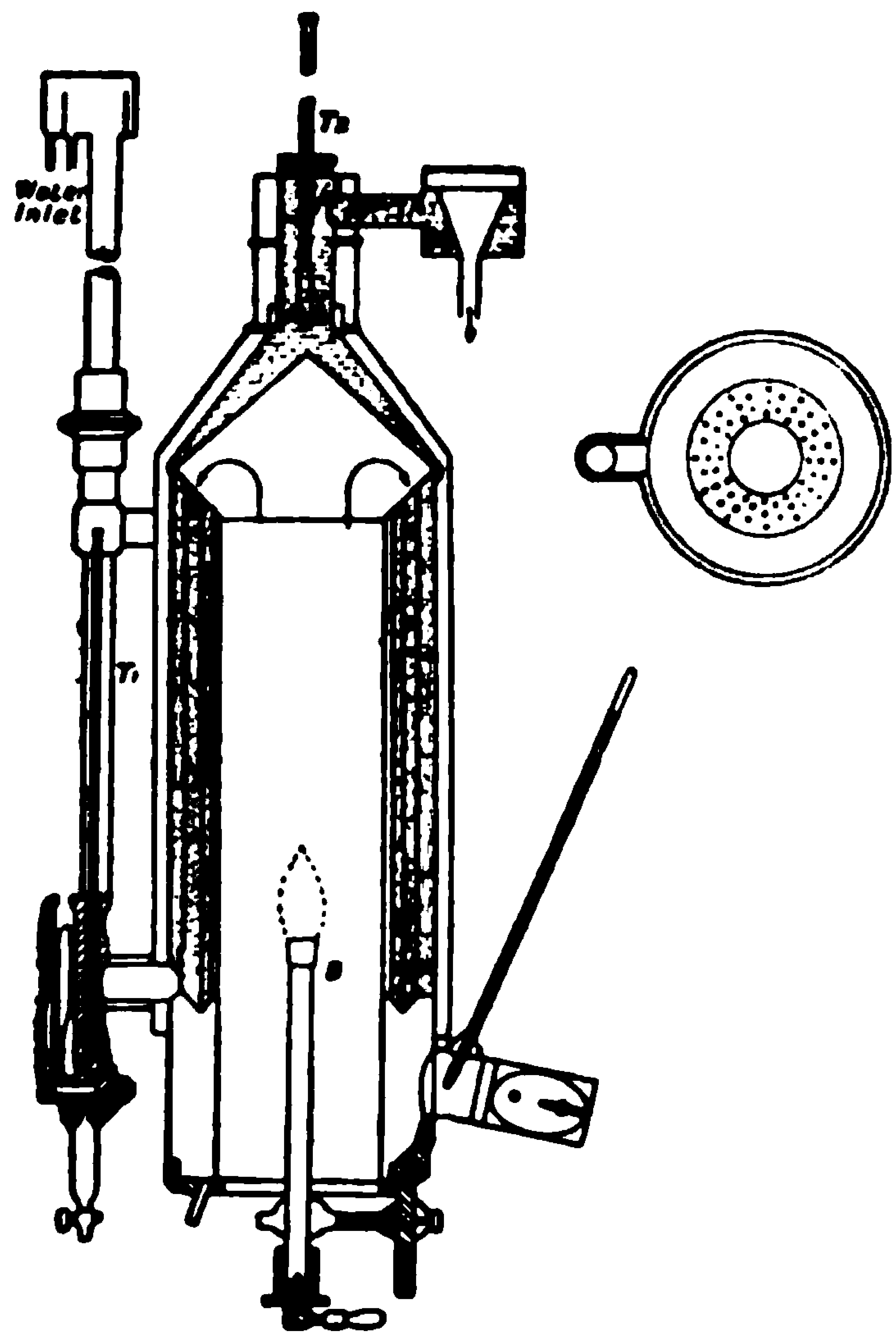

FIG. 85.
JUNKER CALORIMETER.

No engine tests using producer gas can be complete unless the heating power of the gas has been determined, and during the running of the engine test a test of the gas has been made in a "Junker" gas calorimeter. It consists of a cylinder (see Fig. 85) in which a number of tubes are arranged vertically, and in two rows (staggered) through which water is constantly passing. The tubes are heated by a Bunsen burner fed with the gas to be tested, the amount of which is read on a meter, while the gas is kept at constant pressure. The amount of water passing through is measured, as is also the amount of water vapour in the gas. The

inlet and outlet temperatures of the water are taken, from which the calorific value of the gas may be calculated.

Results of a test made on town gas :—

1	Duration of test (minutes)	15
2	Barometric pressure (inches of mercury)	30
3	Gas consumed per minute (cubic foot)	0·11
4	Gas consumed per minute at N.T.P. (cubic foot)	0·111
5	Gas temperature (° F.)	61·5
6	Gas pressure (inches of water)	0·575
7	Quantity of water flowing (lbs. per minute)	3·31
8	Water temperature, inlet (° F.)	49·64
9	Water temperature, outlet (° F.)	69
10	Water vapour in gas (lbs. per minute)	0·0062
11	Calorific value of gas (gross) (B.T.U.) = $\frac{\text{weight of water} \times \text{rise in temperature}}{\text{cubic feet of gas (at N.T.P.)}}$	578
12	Calorific value of gas (nett) B.T.U.)	525

The study of the figures and data given in this chapter will well repay the careful attendant who wishes to make the best of his plant. In the following chapter a few of the calculations will be shown, which, although necessary to derive the above test figures, should not deter the attendant from studying the results of the tests. These last figures are only intended as a guide, and, although not examples of complete tests in the fullest sense of research work, will do much to illustrate how an engine may be expected to work under certain conditions.

CHAPTER XV

CALCULATIONS USED IN TESTS

At the beginning of this book it was stated that very little technical knowledge would be assumed. This, as far as possible, has been remembered, but in the testing of any machinery certain calculations must be made in order to get out the results. These results are to be used as a help to the economical working of the engine and may assist the attendant to take advantage of current literature on the subject of gas and oil power.

(1) Revolutions per minute (R.P.M.) $= \dfrac{\text{Revolutions in test}}{\text{Duration of test}}$

(2) Explosions per minute (E.P.M.) $= \dfrac{\text{Explosions in test}}{\text{Duration of test}}$

(3) Indicated horse-power (I.H.P.) =

$$\frac{\text{M.E.P.} \times \text{Piston area} \times \text{stroke} \times \text{E.P.M.}}{33{,}000.}$$

(M.E.P. in lbs. per square inch; area in square inches; stroke in feet.)

(4) Brake horse-power (B.H.P.) =

$$\frac{\text{Effective load} \times \text{radius of brake} \times 2\pi \times \text{R.P.M.}}{33{,}000.}$$

(Load in lbs.; radius of brake in feet; $2\pi = 6{\cdot}28$.)

(5) Mechanical efficiency (per cent.) $= \dfrac{\text{Brake horse-power} \times 100}{\text{Indicated horse-power}}$

(6) Jacket water per minute $= \dfrac{\text{Water used in test}}{\text{Duration of test}}$

(7) Total gas used at normal temperature and pressure =

$$\text{Total gas used} \times \frac{\text{Pressure of gas}}{\text{Normal pressure}} \times \frac{\text{Normal temperature (abs.)}}{\text{Gas temperature (abs.)}}$$

(8) Total gas per hour (N.T.P.) $= \dfrac{\text{Gas in test at N.T.P.}}{\text{Duration of test (hours)}}$

(9) Total gas per hour per I.H.P. $= \dfrac{\text{Total gas per hour at N.T.P.}}{\text{I.H.P.}}$

(10) Total gas per hour per B.H.P. $= \dfrac{\text{Total gas per hour at N.T.P.}}{\text{B.H.P.}}$

(11) Gas used by burner per hour =

$$\text{Gas per hour} \times \frac{\text{Normal temperature}}{\text{Gas temperature}} \times \frac{\text{Gas pressure}}{\text{Normal pressure}}$$

(12) Heat supplied by gas per minute =

$$\frac{\text{Calorific value} \times \text{gas per hour}}{60}$$

(13) Heat to indicated work per minute =

$$\frac{\text{Indicated work in foot-lbs. per minute}}{\text{778 (Joule's equivalent)}}$$

(14) Heat to water jacket per minute =
(Water outlet temperature − Water inlet temperature) × jacket water per minute.

(15) Heat to burner = gas used per minute × calorific value.

(16) Heat to exhaust, radiation, etc., per minute =
Total heat given to engine − (heat to indicated work + heat to jacket water + heat to burner).

(17) Thermal efficiency (per cent.) =

$$\frac{\text{Heat to indicated work per minute}}{\text{Heat supplied per minute}}$$

In the case of the oil engine, pounds or cubic feet of oil is substituted for gas, and when the producer is used with gas engine the weight of fuel given to the producer is used for calculating the heat given to engine during test. The correct calorific values of the different fuels must be taken. Heat to hot bulb must also be taken into account.

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